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BEFORE PAPYRUS . . . BEYOND RAYON.*

BY

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We wear it; we live in houses made of it; we record our news and literature upon it; we even take it into our systems with our food. What is it? The answer to this riddle is a material which has been responsible for epoch-making changes in the trend of human affairs throughout the long road up from savagery through barbarism and early civilization to the present time. Everyone is familiar with it, yet few know it. It is not only the most abundant material of the vegetable kingdom, but it is also one of the most important materials on which man has relied throughout the development of civilization. We know it in the forms of cotton and of linen; of wood and of paper. We even know it as artificial silk. Yet reference to cellulose, which is the basic chemical substance common to all these materials, brings in a word which is familiar to few. On the other hand, this term cellulose is one destined to become gradually more and more familiar, at least to those who make any pretense of following modern trends in the arts and sciences.

Cellulose has not only exerted an unusual influence on the progress of mankind in the past, but today it is the basic raw material for great industries. Since it forms the structural framework of all trees and plants, it is available wherever vegetable life occurs. Furthermore, it is one of the few raw materials which is capable of periodic reproduction in enormous quantities, and for this reason, if for no other, seems destined to take an increasingly important part in the industrial development of the world.

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* Presented at a meeting held Thursday, October 26, 1933.

Since cellulose is so common in nature, it is only natural that it should have played an outstanding rôle in the history of mankind from the time that early man took the first step out of savagery by accidentally learning how to burn it, until, in the form of a "scrap of paper" it was responsible for developments leading to the Great War in 1914.

Civilization proper is generally considered to have begun with the development of a system of writing, perhaps ten thousand years ago. For this, cellulose can claim no credit since early writings were on clay and stone long before the advent of papyrus. However, when in more recent years cellulose, as paper, became the silent bearer of the written, and later the printed word, it became the messenger of the guiding forces of civilization. It is in this rôle that cellulose has reached its highest significance, making possible many things which had not been feasible before, through the easy and ready dissemination of information to great masses of people.

At about the same time that the manufacture of paper was being introduced into Europe, there were also other developments dependent upon the use of cellulose, which were of such outstanding importance as to have changed the whole trend of civilization. It was in the thirteenth century that Roger Bacon[1] first described black powder, to which he gave the name Philosopher's Egg. How strikingly time has shown the aptness of this picturesque title and what events of first importance have been hatched from it! When used in guns, as it was in the fourteenth century, it put a new power in the hands of the common people and changed the entire social system. Truly did Bacon write, referring to his anagram in which he gave the secret for gun powder. "Whoever will rewrite this will have a key which opens and no man shuts; and when he will shut, no man opens." And an essential part of this "key" was charred cellulose. Again the ready availability of cellulose contributed its part to an epoch-making step in the advance of civilization. Even today charcoal from willow and beech is preferred for the manufacture of black powder.

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[1] Davis, *Ind. and Eng. Chem.*, **20**, 772 (1928).

It has been said that this particular period was a great period of levelling; that gun powder was a great levelling influence downward for the mighty and that the printed page was a great levelling influence upward for the lowly. At any rate paper has now come into universal use throughout the civilized world. It may be only to wrap a bundle or it may be to record a thesis which starts a Reformation. It may be to carry a love message or it may be to announce a Declaration of Independence. It may be merely the kindling which lights the fire on the hearth or it may be the scrap of paper which starts a world conflagration.

To be sure, paper had been known in China for several hundred years before the Christian era, but its use was not established in Europe until about the twelfth or thirteenth century. The story is told that the Arabs were attacked by the Chinese in Samarkand about the middle of the eighth century. The Arabs repulsed their enemies and succeeded in capturing some of the Chinese who knew how to make paper and from them learned the secret. The knowledge of paper-making spread rapidly in Arabia as is evidenced by the fact that there are many early Arabian manuscripts on paper still preserved today, the earliest being dated 866 A.D. Trade with Asia seems to have been responsible for bringing a knowledge of paper manufacture to Greece at about the end of the eleventh century and the Moors established it in Spain in the middle of the twelfth. It gradually spread to Italy, Germany and France so that by the year 1350 the manufacture and use of paper was well established in Western Europe and vellum was gradually superseded.

Today we have many grades and kinds of paper, but all are composed mainly of cellulose, of degrees of purity which vary with the particular kind of paper. At first all paper was made from cotton or linen rags but during the last century wood has become the chief source of supply through the development of chemical methods for separating the cellulose from the other constituents of wood. In 1932 in the United States alone there were consumed about 4,000,000 tons of wood pulp which represents about nine million tons of wood. Of this, a little more than half was of domestic production and the balance imported. The use of a natural resource at so rapid a rate has naturally raised the question as to the steps which should be taken to prevent exhaustion of the supply. To some, the answer seems to be reforestation, while others prefer to rely on cutting trees only above a certain size. By leaving the smaller trees in this way, it has been demonstrated in several sections in the south, that a twenty-year crop cycle is perfectly feasible. Many experts believe that if the cellulose resources of the temperate zone should prove inadequate, the tropics could be relied upon for an adequate supply. Already the rapid-growing bamboo of India is being converted into pulp and studies are being made of the pulp possibilities of varieties of African trees which yield as much or more cellulose per acre per year.

Since cellulose forms the structural skeleton of all vegetable growth, attention is also being focused on annual field crops as possible sources of cellulose. Cornstalks were suggested for paper-making well over one hundred years ago and chemically this has been possible for a long time. However, it is only within the last few years that the economic problems of harvesting, collecting and storage have received the scientific study which is essential if these problems are to be solved in such a way as to make the use of cornstalks economically feasible. The sugar cane also has been the object of considerable attention and many kinds of paper have been produced from it. The application of scientific method in this case has demonstrated in actual farm tests that the per acre yield of sugar cane can readily be increased four to six fold and in special test plots, the yield has been raised to twenty or thirty times the usual average. Even with present yields of corn it is estimated that the United States produces annually about 31 million tons of cornstalks. This is dry weight, free from leaves and husks, and should yield, in the form of paper or board, about 9 million tons, or a little more than the total amount of paper and paperboard produced in the United States in 1932. In other words, assuming the solution of economic problems, such as the collection at a central point of sufficient quantities to permit of operation on a proper scale and the storage of enough material to keep such a mill going for the better part of a year, it still would be necessary to find new outlets for cellulose to make the collection of any considerable proportion of the stover from our annual field crops economically desirable at this time.

In transportation as in so many other activities, man was long dependent on cellulose. His earliest boats, in the form of hollowed logs, were essentially cellulose as were the paddles and later the oars that propelled them. The sailing ships on which man relied until so recently, were made of wood and the cloth of the sails was cellulose in a purer form. Even the modern ocean liner requires cellulose in the form of boat covers, collapsible boats, curtains, deck covering, fenders, hatch covers, life preservers, and tarpaulins, not to mention what might be termed the household requirements such as sheets, towels, upholstery, draperies, and table damask.

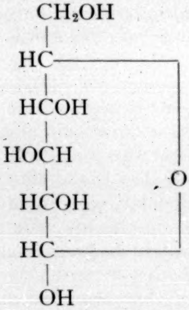
For land transportation, also, man long depended on cellulose. His early sledges and carts were of wood, as were also the stage coaches of a later day. The modern limited train in which cellulose now is only of minor importance, is the outgrowth of experiments conducted only a hundred years ago in which the fuel was wood, the cars were of wood, and in some instances even the rails were of wood. When we turn to the modern automobile, so essential a part as the tires are quite as much cotton cellulose as they are rubber.

While for thousands of years man had turned to cellulose for so many of his needs, it had, until the last one hundred years, always been as the naturally occurring cellulose or as the simple derived products, charcoal and paper. With the development of chemistry it was only natural that chemical derivatives of cellulose should begin to make their appearance. The surprising thing to any critical observer might be that the chemistry of cellulose was so slow in developing since the use of cellulose itself was centuries old. To the chemist on the other hand, the reason is quite apparent, for it is only a relatively short time that even the empirical composition of cellulose has been known. For some time that was all the information available since cellulose could not be crystallized nor could its molecular weight be determined. Little by little the chemistry of cellulose has been unfolded and although we do not yet know the whole story, it is nevertheless being recognized that in cellulose, mankind has a chemical raw material available in enormous quantities and a substance the supply of which can be annually replenished when economic conditions become such as to warrant it.

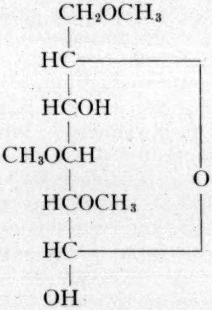
At this point it may be of interest to digress a moment to survey briefly the development of industrial organic chemistry. It started with the distillation products from coal as its raw material and separated from this complex mixture various substances of the so-called aromatic series, from which were synthesized at first dyes, and later perfumes and medicinals. In each case, however, the product was a definite solid or liquid compound with well defined molecular properties. About ten or twelve years ago a second division of applied organic chemistry appeared, which has since grown to what might almost be called a heavy organic chemical industry. It starts with the simplest aliphatic hydrocarbons such as ethylene and builds up from there aliphatic products which find wide use in industry, many of them as solvents. The synthetic processes have even been carried to a point where various polymerized molecules have been produced to give solids with colloidal characteristics such as the vinyl resins and the so-called synthetic rubber. At this point this second division of applied organic chemistry meets the third, which uses cellulose as raw material. Here we have a substance which occurs naturally in the form of a highly polymerized molecule and the uses of it and its derivatives depend in large degree upon the retention of these colloidal properties.

In spite of the fact that industries using cellulose are centuries old, it is only for a relatively short time that we have known even that its empirical composition was $C_6H_{10}O_5$. At first, it was thought that there were four hydroxyl groups in the $C_6H_{10}O_5$ unit, and I can well remember a lively discussion at one of the meetings of the American Chemical Society not more than twelve years ago as to whether there were four hydroxyl groups or only three. It is now generally recognized, that there are only three hydroxyl groups in the elementary cellulose unit but it was not until about eleven years ago that their character was known.

This question was answered very prettily by Denham and Woodhouse by repeated treatments of cellulose with dimethyl sulfate in the presence of alkali. On hydrolyzing the methylated cellulose with weak acid they obtained chiefly 2, 3, 6 trimethyl glucose which may be represented



Glucose



2, 3, 6 Trimethyl Glucose

Since there are two free hydroxyl groups in the trimethyl glucose, it is apparent that these could not have been present in the original cellulose molecule but must have been produced during the hydrolysis. The methylated ones are the ones which were originally present in the cellulose and since the constitution of trimethyl glucose is known, it follows that in cellulose there must be three and only three hydroxyl groups, one of which is a primary hydroxyl group and the other two secondary. Since the empirical composition of cellulose is $C_6H_{10}O_5$ and that of glucose $C_6H_{12}O_6$, it is obvious that cellulose is made up of anhydro-glucose units.

This statement, however, would hardly suggest the exceedingly complex character of the cellulose molecule. Although externally cellulose and its derivatives always appear as amorphous or colloidal materials, nevertheless, the X-ray has shown them to possess definite crystalline characteristics. The unit cell responsible for the crystalline properties is believed to consist of four glucose residues. It is now believed that these unit cells are bound together by primary valences into long chains of what might be termed anhydro-glucose residues, and that these primary valence chains are in turn bound together by secondary valence forces to form the micelle. This basic idea has been extended and elaborated to account for the structure of the cellulose fiber, including its high longitudinal strength, the orientation about the long axis of the fiber, and the presence of the outer layer of fibrils in the cellulose fibers from wood.

Thanks to recent investigations by Staudinger, by Freudenberg, and by Stamm, we even have some conception of the molecular weight of cellulose. While these figures do not agree, nevertheless, they at least indicate that the molecular weight is very high. Staudinger, for example, has found that cellulose from purified cotton has a molecular weight of 190,000 and he feels that even this may be on the low side. Freudenberg has calculated the molecular weight to be in the neighborhood of 8100, although he admits this is probably too low. Stamm, using the ultra-centrifuge, has obtained a molecular weight in the neighborhood of 40,000.* In this connection it is of interest to note that Staudinger and Schweitzer found that rayon made by the cuprammonium process has a molecular weight only about one-sixth that of purified cotton, and Stamm found that the cellulose in wood pulp consisted largely of material having a molecular weight about half that of cellulose from carefully purified cotton.

Although the use of cellulose as a technical raw material did not wait for our present day knowledge of the structure of the cellulose molecule, nevertheless, the more we know about the inner chemistry of cellulose, the more rapidly do its uses expand.

The first chemical derivative of cellulose to assume importance in our present day civilization was the nitrate. When a properly purified cellulose is treated with a mixture of nitric and sulfuric acids, a series of nitric acid esters of cellulose is formed. Those which contain about eleven per cent. of nitrogen are the basis of the pyroxylin plastics such as celluloid; those with about twelve per cent. of nitrogen are used for artificial leather and lacquer finishes; while those with a higher percentage of nitrogen constitute our smokeless powders. The significance of the last for present day civilization needs no comment. The modern pyroxylin finishes, as represented by quick-drying lacquers, have been as effective in their way in increasing man-hour output as has power machinery in other ways. Nitrocellulose and cellulose acetate, as the basis of the moving picture film, have given us a means of recording events in action and in sound as they previously had been recorded in story on cellulose in the form of paper.

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* Since writing the above, the author has been advised privately that recent and more accurate determinations have placed the molecular weight of carefully purified cotton cellulose at 300,000.

One of the uses of transparent sheets of cellulose ester plastic which is now receiving considerable attention in the public eye is in the manufacture of laminated glass such as is finding increasing use in the modern automobile. This glass is made by cementing a specially prepared sheet of cellulose plastic material between two pieces of glass. The product as used in windshields is of about the same thickness as ordinary plate glass but it does not shatter nor do the pieces fly when the glass is broken. A further application of the same principle is in the manufacture of bullet-proof glass. This is composed of five laminations. The center one is usually a piece of plate glass about three-quarters of an inch in thickness. To each side of this is cemented a sheet of cellulose plastic and on the outside of each of these layers of plastic there is cemented a piece of thinner plate glass, making a composite piece a little over an inch thick. Such material resists bullets even at close range and is finding use in the windows of armored cars and cashiers' cages in banks.

Up until very recently the plastic used for this purpose was made from cellulose nitrate. This was not ideal for the purpose because it gradually discolored in the light. However, considerations of cost compelled its use. Within the last year or so, however, a revolutionary change in the method of manufacture of these plastics has so lowered the cost of the finished sheets of cellulose acetate plastic that at the present time it is estimated that over 70 per cent. of all the laminated glass manufactured in this country is made with cellulose acetate plastic. The manufacturing improvement responsible for this surprising change consists in replacing a long series of batch operations by a single continuous process which cuts the time of production from ten or twelve days to the corresponding number of hours; and since the material is totally enclosed during its manufacture, practically the total production is of first quality.

When attention is turned to the manifold applications of cellulose and its derivatives in modern civilization, it becomes quite apparent that cellulose is not only nature's riddle but also nature's paradox. Cellulose in the form of wood has long been used as a material of construction because of its resistance to atmospheric conditions, yet at temperatures slightly under that of boiling water, cellulose slowly combines with oxygen and decomposes. Again cellulose in the form of cotton is widely used for clothing because of its resistance to washing and to the chemicals usually used in that operation, yet two samples of cellulose, identical except that one has been boiled in distilled water for two hours and then dried, exhibit markedly different chemical characteristics.

We therefore find that to supplement the age long uses of cellulose which have been dependent on its resistance to chemical change, there is now springing up a long list of uses which depend upon its chemical reactivity. If cellulose in the form of cotton thread or fabric is treated with an eighteen per cent. solution of caustic soda in the cold and dried under tension, there is obtained the well-known effect of mercerization which produces a silky finish on cotton fabrics. On the other hand, if sulfuric acid of about seventy per cent. strength is used instead of the caustic soda and the acid thoroughly washed out, there is obtained the material known as vegetable parchment, which is sufficiently water resistant so that it has been sold to replace cloths in dish-washing. Paper is the form of cellulose used for this treatment. When special forms of paper are employed, the product makes an excellent electric insulation. Treatment with concentrated solutions of zinc chloride produces a somewhat analogous effect, the product being known as vulcanized fiber which finds many uses in industry as for example in roving "cans" so-called, and trucks for textile mills.

For centuries cellulose in the form of linen and cotton has provided wearing apparel. Almost our earliest literature speaks of purple and fine linen. Yet silk was always the fabric of the nobility and had a beauty and a feel which the cellulose fibers could not match. Since the sheep converted the cellulose of hay and grass into wool and the silk worm changed the cellulose of the mulberry leaf into silk, man has long been trying to find the secrets, particularly that of the silk worm. The natural raw material with which to experiment was cellulose, at first that of the mulberry leaf and later a purified cellulose. While the silk worm's secret has not yet been found, ways have been developed, after years of research, for producing from cellulose, fibers which are as attractive as silk to both eye and skin. In the four forms of rayon we have the first man-made fibers and fibers which, therefore, are not subject to the whims of nature for their production.

The goal for which the early investigators in this field were striving, was the production of natural silk by artificial means. In fact it has been said that its earliest designation, artificial silk, was given to the new product in order to distinguish the silk made by artificial means from that made by nature. It is well known now, however, that none of the four varieties of rayon are in any way related chemically to silk. The first three to be developed are all regenerated cellulose and quite similar in their properties, although the series of changes through which they have passed from cellulose to finished product are in each case quite different. The latest member of the group is cellulose acetate, a chemical compound of cellulose and acetic acid and quite different in its properties from either cellulose or the other forms of rayon.

In general the processes for the manufacture of synthetic fibers may be divided into two classes, depending upon whether the finished fiber is essentially cellulose, regenerated in a somewhat modified form, or whether it is a compound of cellulose such as cellulose acetate. All of the processes have certain underlying principles in common, involving first the conversion of the cellulose into a soluble derivative, the solution of which is then forced through very fine orifices into a hardening medium which may be either a liquid or a gas, depending upon the character of the solvent. In the earliest process, the cellulose was converted to cellulose nitrate which was dissolved in a mixture of alcohol and ether, and this solution, after careful filtration, was squirted through fine orifices into a stream of warm air which caused the solvent to evaporate leaving fine filaments of cellulose nitrate. The solvents were recovered and the fibres subjected to an alkaline saponification treatment for the purpose of reducing their inflammability. This left them finally in the form of regenerated cellulose. This process is now being used by only a single company in the United States.

Another process takes advantage of the solubility of cellulose in cuprammonium solutions. In this case the deep blue, viscous cellulosic solution passes from the fine orifices directly into a liquid regenerating bath which may be either a dilute acid or a dilute alkali. After being freed from copper, these fibers also are composed of regenerated cellulose.

The process by which at least 80 per cent. of the artificial silk is produced today, is the viscose process. In its barest outline it consists in treating purified cellulose with caustic soda solution, followed, after a suitable aging period, by treatment with carbon bisulfide which produces a cellulosic compound soluble in dilute alkali. This also is ripened and then squirted into dilute sulfuric acid which breaks down the soluble compound and regenerates the cellulose.

In all of these three processes it will be noted that the finished fibers are composed of a modified cellulose. In the fourth commercial process and the one which just now is expanding at the most rapid rate, the cellulose is converted into cellulose acetate and the finished fibers are composed of the same material. The solvent is usually acetone and the solution is ejected from the orifices into a stream of air in which the acetone evaporates and from which it is recovered. One of the advantages of this process is that the fibers require no further chemical purification treatment before they are ready for what might be called the textile operation of twisting.

When artificial silk first appeared on the market it was rather coarse and somewhat harsh in its feel. Since then, however, there have been marked improvements in the strength of the fibers and, also, there has been a general tendency toward reducing the size of the individual filaments as well as the size of the threads. Perhaps one of the most remarkable developments in the rayon industry in recent years has been the marked increase in the demand for fibers in which the normally high luster has been reduced. Originally artificial silk achieved popularity because of its high luster, yet today considerably more than half of all the rayon produced has the luster more or less reduced.

Still another trend which is worth noting, is the increasing popularity of synthetic fibers made from cellulose acetate. This was the last of the four varieties to achieve commercial importance, and at first its high cost deterred its wide use. Recently, however, there have been reductions in the price and with these have come wider markets.

When rayon, or artificial silk as it was then known, first began to attract attention in this country, a committee of silk manufacturers was appointed to study this new competitor and report on its possibilities. After careful deliberation the committee finally concluded that the possibilities of the new fibers were distinctly limited and that they would probably be short lived. Yet in 1931 60 per cent. more rayon was used in the United States than natural silk and this year the proportion in favor of rayon is probably even higher. Rayon, however, should not be looked upon as a substitute for silk, but rather as unique fibers with distinct and valuable properties of their own. These fibers may be used alone in fabrics; in conjunction with cotton to furnish an attractive decorative effect; or with wool to produce pleasing new fabrics of lowered cost. New applications are constantly being found. In 1910 the production of rayon in the whole world was only about ten million pounds and none was being made in the United States. In 1928, on the other hand, one hundred million pounds were turned out in the United States alone, and in 1931 the production here amounted to about 144,000,000 pounds, the figure for 1932 being 10 per cent. less than for 1931.

In spite of the rapid developments of the last few years, it is doubtful whether the real significance of these new fibers has yet been visualized by anyone. When first produced in this country twenty years ago they lacked strength and resistance to water but improvement in these and other directions has been constant. A special type of rayon fiber has been developed which rivals silk in appearance and strength even when wet, though certain other characteristics have thus far prevented its wide introduction into the textile industry.

Even beyond rayon, cellulose is continuing to be a powerful aid in making possible new developments which are changing the whole trend of civilization. For the airplane, as in earlier forms of transportation, cellulose was the first material to which man turned. The framework and propeller were made of wood, the wings were covered with cellulose in the form of linen or cotton fabrics and these in turn coated with cellulose nitrate or cellulose acetate varnishes to render them taut. Whatever the future of the metal airplane, the availability of cellulose and its remarkable adaptability have helped markedly in the progress of aviation.

The merchandising of packaged articles is today dependent to a very large extent upon cellulose. The large container or carton is made from paper-board as are the smaller boxes which hold the individual units of merchandise. To increase the appeal to the eye, the chemist in recent years has furnished transparent sheets of Cellophane and Sylphwrap. The chemistry involved in the manufacture of this material is the same as that of the viscose process for manufacturing artificial silk, but instead of extruding the cellulosic solution through minute orifices, it is forced through a long narrow slot into a hardening bath.

Another new use for a cellulose derivative is in the manufacture of shoes. In this novel process all sewing or nailing of the sole is eliminated, and the shoes are literally stuck together. The cement used is a specially compounded cellulose nitrate cement, with unusually rapid sticking qualities. When the process was first used in the United States in 1928, the soles had to be held in contact with the uppers for thirty minutes. At the present time the process has been so perfected that it is now only necessary to hold the two parts together for 50 seconds. The process is so rapid that a single operator in 8 hours and 15 minutes applied soles to 1580 pairs of shoes. The indications are that over 50,000 pairs of shoes will be made by this method in the United States in 1933.

In this new age, cellulose has taken its place as a great chemical raw material and with increasing knowledge its importance is bound to be enhanced. Technical literature and patent indices are recording at an increasing rate new chemical derivatives of cellulose, many of which may reasonably be expected to appear in industry within the next five or six years. Already cellulose ethers are available, some of which have a very unusual resistance to both acid and alkaline solutions. Reports are also being heard with increasing frequency of new mixed esters with greatly improved properties. It is only the complex chemical character of cellulose that has so long delayed its utilization as a raw material for chemical transformation, but as the nature of the cellulose molecule continues to be elucidated, a material of which so large a supply is potentially available will surely find useful application in increasing quantities.

Argonauts of Science.—In this year's first issue of *The Pittsburgh Record*, DR. WILLIAM A. HAMOR, assistant director of Mellon Institute of Industrial Research, reviews some of the numerous achievements wrought by its workers in research during the years following the founding by A. W. and R. B. Mellon in 1913. At the present, about one hundred scientists are at work on fifty-five industrial fellowships, each relating to a specific subject.

A group of four fellows is engaged in research on new building materials which so far has resulted in the invention of a bonded metal, a hard-finished protected metal and a keystone-beam steel floor. On another fellowship three specialists are developing novel varieties of strained vegetables and also new cereal products. A large chain of department stores has two chemists who are carrying on an extensive program of evaluation of merchandise and the maintenance of standards of quality. A large petroleum refining company has a staff which has added importantly to drilling practice, to the chemical treatment of wells to increase oil production, and to the knowledge of corrosion and its inhibition.

There is a fellowship that is studying economic factors in the use of fuels and procedures for contending against municipal air pollution problems. Fellowships on heating, heat insulation, natural gas, petroleum refining and anthracite having accounted for many successful developments. A shoe fellowship has evolved a new leather having increased durability, waterproofness, polishability and resistance to scuffing. Research chemists sponsored by a large manufacturer of synthetic organic chemicals have, among other things, worked out commercially feasible processes for the production of ethylene, an anesthetic; Prestone, an anti-freeze; Cellosolve a dye solvent; Carbital, for textile finishing; the vinyl resins; and Carboxide, a fumigant. C.

Wet Shavings and Pears.—(U. S. Department of Agriculture Clip Sheet No. 810.) In order to protect pears from freezing during transportation in moderately cold weather, specialists of the U. S. D. A. have devised the scheme of placing wet shavings on the floor of the refrigerator car. This represents the practical application of a well-known physical law—that freezing water gives up heat. Thus if a certain amount of heat must be conducted away for every degree the water is cooled, when it reaches the freezing temperature seventy-nine times as much heat must be removed before the water is completely transformed into ice and the temperature once more begins to drop. Since pears can readily withstand temperatures as low as the freezing-point of water they are protected so long as any water remains unfrozen in the shavings. C.

STRUCTURAL ANALYSIS BY ELECTRIC CIRCUIT ANALOGIES.

BY

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ABSTRACT.

Electric circuits may be constructed which obey the same laws as structures under load. Measurements on the circuits will then give the stresses, deflections, etc., of the corresponding structures. Circuits are given for determinate and indeterminate pin-connected and rigidly-connected structures in the static and the dynamic state. Experimental work is reported on relatively simple typical cases to show the apparatus and methods of measurement which are applicable, and the precision obtainable.

Structures may be analyzed by three principal methods. First is the method of setting up the governing equations and solving them formally, in some cases by the use of approximations which greatly shorten the work. Second, mechanical models may be examined, as with a shaking-table, usually with the aid of the principle of dynamic similitude. Third, an analogous electric circuit, which is governed by the same equations as govern the structure, may be prepared and measured, and the results interpreted to give the behavior of the structure. All three of these methods will have fields of usefulness, but the last has not yet been developed to the point where its utility may be evaluated. Hence, in this paper, a wide range of treatment of structures by electrical analogy will be presented, with the realization that experience will be necessary to indicate parts of the method worthy of further development.

The purpose of this paper is hence to develop a method of analysis of structures by means of measurements made upon analogous electrical circuits. It will be shown to be possible, by means of circuits of reasonable complexity, to treat indeterminate as well as determinate pin-connected or rigidly-connected structures in either the static or the dynamic state.

Under the dynamic state can be treated impact, or generally variable loading, or the impression of forced motions such as occur in earthquakes. Attention will first be given to pin-connected structures, and the method will then be extended to include rigidly-connected frame structures. The measurements will yield the stresses and deflections with reasonable precision. Two dimensional or three dimensional cases may be treated.

This method is furthered by two fundamental ideas: first, the simultaneous use of several interconnected networks to represent a single structure, or the use of several inductances or capacitances to represent a single mass point; and second, the use of ideal transformers to produce proportionality. Any structure in the static state is governed by a set of simultaneous algebraic equations, and to obtain a solution it is simply necessary to construct and measure an electric network which is governed by this same set of equations. In this process it is convenient to produce equality by using transformers and by applying alternating potentials to the network. In the dynamic state the structure is governed by a set of linear differential equations. An electric circuit governed by the same equations may then be measured by oscillograph to yield the time-variation of the transient stresses and deflections of interest under variable loading.

There are always a large number of equivalent electrical networks which may be made to obey the same laws as those that govern the performance of a given structure of moderate complexity. The simplest of these might be chosen for use. In some ways however, it is preferable to use a scheme whereby the network may be set up by inspection of the structure itself, and without the necessity of writing down the equations involved even though the resulting network is then somewhat more complicated. This is the procedure of this paper. The method lends itself to the construction of an electrical calculating table for structural analysis. Such a table would consist of a congeries of standard electrical elements with provision for interconnecting them rapidly in proper manner by direct comparison with the interconnection of the elements of the structure under analysis, and with provision for accurate measurement of those electrical quantities which represent the desired stresses and deflections in various members. This procedure is similar to that used by electrical engineers for the study of the behavior of complicated electrical power systems. An electrical replica of the system under study is set up and measured in the laboratory. The most complete representation is obtained by using an alternating current network analyzer.[1] It is the purpose of the present paper to develop a corresponding method whereby the analysis of complicated structures may be carried through in cases of such complexity that the usual methods of analysis become prohibitively laborious.

The corresponding method for power-system analysis required many years of development, and a considerable cost, in the construction of calculating-tables and network-analyzers before becoming generally useful; but at the present time important studies of power systems may be rapidly and accurately carried out in the laboratory in cases where the complexity involved would render the analytical solutions entirely impractical from the standpoint of cost and time required. It is hoped that a development of similar electrical methods for structural analysis may be developed to the point where studies may be undertaken at justifiable cost of complex indeterminate structures under both steady and variable load conditions, with a considerable reduction in time and cost, thus making possible studies which are now too laborious to be economically justifiable.

The basic idea of the treatment of mechanical systems by means of measurements on analogous electrical circuits appears in several places in the literature.[2] The general scheme is to produce an electrical network governed by the same set of differential or algebraic equations as the mechanical systems, and subject to the same system of constraints, to set up the analogy between mechanical and electrical quantities, with convenient conversion factors, and then to measure the electrical quantities in order to obtain the value or time variation of the corresponding mechanical quantities. For static problems of determinate or indeterminate structures the work of Mallock is outstanding.[3] This treats the solution of simultaneous linear algebraic equations with real coefficients by electrical measuring methods in a general manner, and hence provides a way of solving static problems of structures. The appearance of Mallock's excellent treatment has made it possible to greatly shorten the present paper, although the consideration of static cases is still included largely because the method of approach is here directly from the structure to the network, rather than by first setting up the governing equations, and also because of certain differences of detailed treatment.

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[1] Travers and Parker, "An Alternating Current Calculating Board," *Electrical Journal*, May 1930. Hazen, Schurig and Gardner, "The M.I.T. Network Analyzer," *Trans. A.I.E.E.*, **49**, No. 3, July 1930, pp. 1102–1113.

[2] For example: C. A. Nickel "Oscillographic Solution of Electromechanical Systems," *A.I.E.E. Transactions*, **44**, 844 (1925); H. H. Skilling, "An Electric Analogue of Friction for Solution of Mechanical Systems," *Trans. A.I.E.E.*, Sept. 1931, p. 1155; Chapter 16 of "Operational Circuit Analysis," J. Wiley & Sons Co., by V. Bush.

Considerable use will be made below of an "ideal" transformer. This is a transformer in which, under the conditions of use and to the degree of approximation necessary for accuracy of results, the primary and secondary currents or voltages are always in a fixed constant ratio. Such a transformer will ordinarily be built with a nickel-iron alloy core and closely coupled windings. In the case where primary and secondary currents are to be always in a certain ratio, the same conditions hold in the transformer design as hold for current transformers used in measurement work. The flux density should be low, and the primary turns sufficient so that the exciting current is negligible compared to the work current. Frequency should be high in order to reduce size, but low enough so that the currents flowing through distributed capacities will also be negligible compared to the work current. In some cases the transformer leakage reactance should be small. A similar set of conditions can readily be stated when it is desired to maintain a fixed ratio of voltages. A transformer of this sort, inserted in an electrical network, forces substantial equality or proportionality between two electrical quantities.

Another important artifice used below is the treatment of stresses and reactions in each dimension separately. A single mechanical system thus becomes represented by two electrical networks, in the case of a structural problem in a plane, or by three networks in the case of a three-dimensional problem. These networks are interconnected, and together they represent a single structure. When the inertia of a mass point is to be represented, the equivalent electrical element appears in each of the networks. When a diagonal structural member appears, its reaction is introduced into the several networks by transformers of correct ratio.

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[3] R. R. M. Mallock, "An Electrical Calculating Machine," *Proc. Royal Soc.*, **140**, No. A841, May 3, 1933, p. 457.

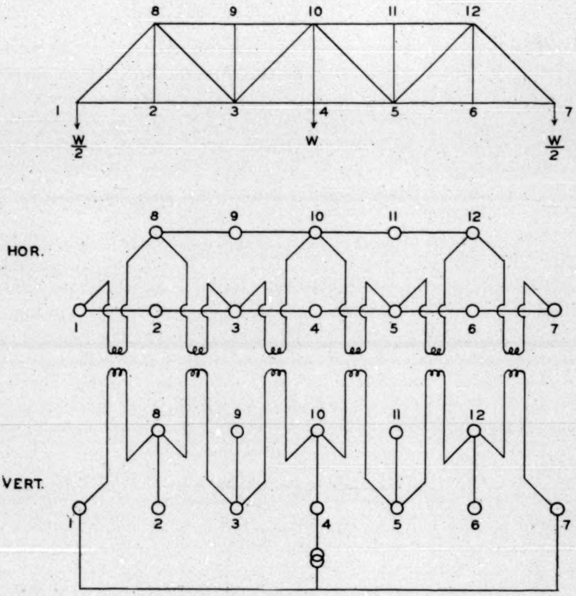
The simplest problem to be treated is that of the static stresses in a determinate structure such as a truss in a single plane, and having pin joints. This will be discussed, not because of the value of the results, for those can be obtained very easily by graphical methods, but in order to illustrate principles which are used in more complicated problems. An example will be treated from which the general application will be evident.

Consider the truss of Fig. 1, with a single load at its center. The procedure of setting up the electrical networks is as follows: make two diagrams, one for horizontal and the other for vertical stresses, locating points in each by correspondingly numbered panel points. In the horizontal network connect together each pair of panel points which in the structure are connected by a horizontal member. Similarly, in the vertical network, connect each pair which in the structure are connected by a vertical member. In both networks connect each pair which in the structure are connected by an inclined member, but interpose in these connections in each case a transformer, the primary of the transformer being inserted in the connection of the horizontal network and the secondary in the connection of the vertical network. Let the ratio of each tarnsformer be such that the current in the horizontal network connection bears the same relation to the current in the vertical network connection, that, in the structure, the horizontal stress in the member bears to the vertical stress. In other words, let the ratio of the transformer, measured as the ratio of secondary to primary current, equal the tangent of the angle of inclination of the member with the horizontal.

At the point where the vertical load is applied, in this case panel-point 4, bring out a lead from the vertical diagram, and insert in this lead a source of alternating current A. The return leads are connected to the diagram at the points of reaction of the supports.

Now the method of using the network is simple. Adjust the current at A to any convenient value I, using any frequency suitable for proper transformer behavior, and let this current represent the load W. To get the stress in any horizontal or vertical member read the current in the corresponding connection and multiply by W/I. To get the stress in an inclined member read the current in either vertical or horizontal connection and multiply by W/I and by the cosecant or secant respectively of the angle of inclination.

FIG. 1.



The proof of the procedure so far may be very brief. At a panel point of the horizontal network Kirchhoff's law states that the sum of the currents in the connections leading to that point is zero. The corresponding statement for the structure is that, at a panel point, the sum of the horizontal components of the stresses in the connecting members is zero. Similarly, for the vertical network and vertical stresses. There is hence a one-to-one correspondence between currents in the horizontal network and horizontal stresses in the structure, and between currents in the vertical network and vertical stresses in the structure. Exactly the same laws apply to currents in one case as apply to stresses in the other, and in each case these laws are sufficient to fix the distribution. Hence we have an accurate analogy.

The extension to more complicated problems of this general nature is now simple. If there are several loads, then there will be several sources of alternating current, and each current must be adjusted until its magnitude represents to scale the corresponding load. If there is no symmetry, then a separate source must be used to adjust the reactions. All the sources must be adjusted so that the currents supplied are strictly in phase. If there are horizontal loads, or horizontal components of loads, they are handled by sources connected to the horizontal network.

If the problem is a three dimensional one, three networks are necessary. All panel points appear in each network diagram, although, since there is no need that they be placed in their correct geometrical relationship, they can all appear in a plane for convenience. Connections are made as before. A member located in a principal plane is treated exactly as above. When a member is inclined with respect to all three axes the corresponding electrical connections are interrelated by transformers in such manner as to preserve the correct relationship between all three components of stress, two transformers being necessary for this purpose. The rest of the procedure is self-evident.

In this type of problem the only circuit elements utilized are current transformers. The only voltages appearing are those due to the flow of currents through the leakage reactances and internal resistances, and these should be small and immaterial. The single criterion for accuracy is that the exciting currents of the transformers, sufficient to produce these small voltages, shall be negligible compared to the currents measured.

In a problem of the sort illustrated in Fig. 1, symmetry may be made use of, and only half of the circuit actually set up. The inclinations of the inclined members are all equal, and hence all the transformers may be of the same ratio. Moreover, by using different conversion factors for the two networks, transformers of unity ratio may be utilized. In other words the factor due to the angle of inclination may be introduced into the computations rather than into the transformer ratio. Some of these devices may be useful in connection with later and more complex problems.

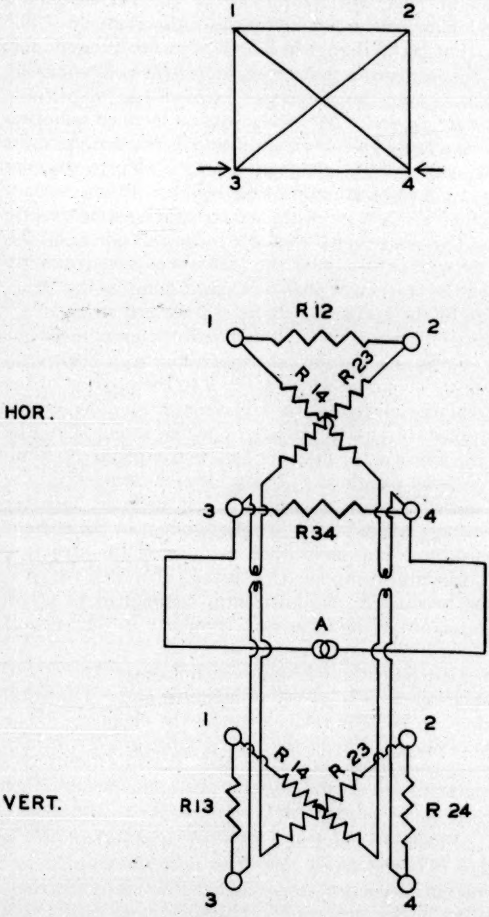
There will next be considered the much more important problem of the indeterminate structure, still with pin connections, and at present with static loads. Again we will consider an explicit example, from which it will easily be possible to generalize.

Consider the simple indeterminate structure of Fig. 2. We now have to consider the compliance of the members and we will call *Rmn* the compliance of the member connecting points *m* and *n*. This is the change in length of this member produced by unit axial stress.

As before we make two diagrams, one horizontal and the other vertical, and number the panel points. In the horizontal network connect all pairs of points which in the structure are connected by a horizontal member, but into this connection insert a resistance proportional to the compliance of the member. In the figure this resistance is shown labelled as equal to the compliance, but any convenient conversion factor may be used and employed in the final comparisons. Proceed similarly in the vertical network. Where inclined members appear, place the corresponding resistance in both networks, and interconnect the two networks at this point by means of a transformer, the ratio of which is chosen just as outlined above for determinate structures.

Load is applied as before. In the example under consideration a horizontal load is shown at points 3 and 4. This is represented by a source of alternating current connected as

FIG. 2.


1
2
3
4
R 12
R 14
R 23
HOR.
3
R 34
4
A
1
2
VERT.
R 13
R 14
R 23
R 24
3
4

shown. Adjust this current to a convenient value, and obtain the stresses in members by measuring the corresponding currents and using conversion factors as outlined above. The deflections, that is the change in length of members, may now be obtained by measuring the voltage across the corresponding resistances and using the conversion factor setup when these resistances were chosen. Measurements on inclined members in the two diagrams give horizontal and vertical deflections respectively, and to obtain the total length change we may take the square root of the sum of the squares of these values.

The analogy between currents and stresses is set up exactly as before. The statement that, at a panel point in the horizontal network, the sum of the currents is zero, is exactly analogous to the statement that at a panel point in the structure the sum of the horizontal forces is zero, and so on.

The analogy between voltages and deflections comes about as follows: Across a resistance corresponding to a horizontal member appears a voltage which is equal to the product of the resistance and the current. In a horizontal member of the structure appears a change of length which is equal to the product of the stress in the member and its compliance. Similarly for vertical members. Across the resistance in the horizontal network corresponding to an inclined member appears a voltage which is equal to the product of the current and the resistance. In an inclined member of the structure appears a horizontal component of change of length which is equal to the product of the horizontal component of stress and the compliance of the member. Similarly in the vertical network.

Moreover, we have the following relationships: The rate of power dissipation in a network element is I^2R. The total power dissipation is ΣI^2R taken over all the elements. The distribution of currents in the network will be such as to make this a minimum, that is,

$$\delta\Sigma I^2R = 0.$$

The potential energy stored in a member of the structure is $P^2R/2$, where P is the stress and R is now the compliance. The total potential energy stored is $\Sigma P^2R/2$. The distribution of stresses in the structure will be such as to render this total stored potential energy a minimum, that is,

$$\delta \Sigma P^2 R = 0.$$

Thus the distribution of currents in the network is controlled by exactly the same law as is the distribution of stresses in the structure.

Note must be taken, however, of the fact that we have two networks and one structure, and that the network currents represent stress components. That the relationship still holds under these conditions is shown as follows: The minimum dissipation relationship holds for either network alone, giving

$$\delta \Sigma I_x^2 R = 0$$

and

$$\delta \Sigma I_y^2 R = 0,$$

where I_x and I_y are currents in corresponding elements of the horizontal and vertical networks. To every term in the first equation corresponds a term in the second which involves the same value of resistance, with the remark that where vertical or horizontal members are involved one of the component currents is zero. We can therefore add, and obtain

$$\delta \Sigma (I_x^2 + I_y^2) R = 0.$$

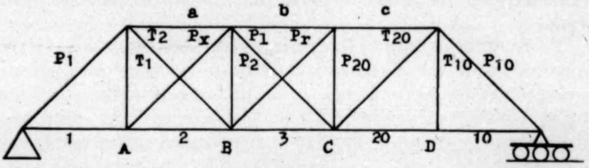
But $I_x^2 + I_y^2$ is the quantity which we consider analogous to P^2. Our analogy is hence complete.

In order to examine the accuracy obtainable with apparatus of the usual type, a problem involving the static stresses in an indeterminate pin-connected truss was worked out analytically and experimentally for comparison.

The problem investigated is shown in Fig. 3, which gives the essential mechanical dimensions. There are two indeterminate panels, and the slope of all slanting members is 45°. One to one current transformers are therefore required. The resistances in ohms were made equal to the ratio of length in feet to area in square inches of the members. The transformers used were of the usual commercial type of instrument transformers, rated 5 amperes, 80 watts. Tested for ratio, the error with 3.2 ohms load was less than 0.1 per cent. from 0.5 to 5.0 amps. With 13 ohms load the error was less than

2 per cent. at 0.5 amps., and decreased with increase of current. The use of these transformers for this problem was therefore considered satisfactory.

Fig. 3.



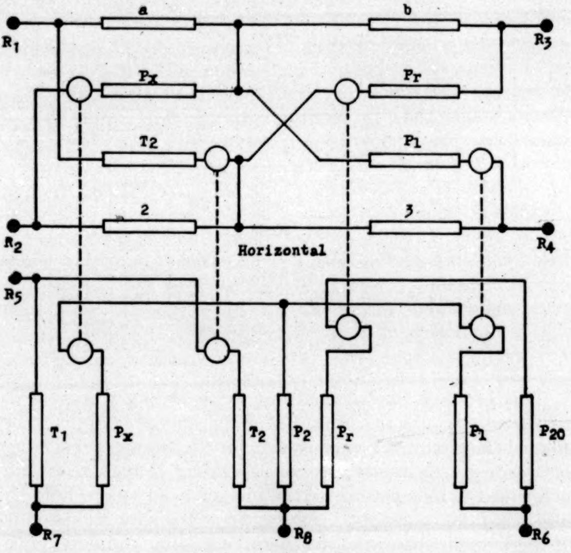
Member.	Length/Area, ft./sq. in.	Length, Feet.
P_1	1.01	42.4
T_1	2.143	30
T_2	3.030	42.4
P_x	3.030	42.4
P_2	3.333	30
P_l	3.535	42.4
P_r	3.535	42.4
P_{20}	3.333	30
T_{20}	3.030	42.4
T_{10}	2.143	30
P_{10}	1.010	42.4
a	.769	30
b	.769	30
c	.769	30
1	1.364	30
2	1.364	30
3	.937	30
10	1.364	30
20	1.364	30

Pin connected truss problem.

The circuit used to represent the two indeterminate panels is shown in Fig. 4. The primaries and secondaries of the current transformers are indicated by circles, and the cores by dotted lines, for the sake of clarity. The external loads on the structures are applied through the reactions labelled *R–R* in the figure. The results are indicated in Table I, which compares the calculated stresses with the observed.

In setting up this problem it was found that the transformers used had a sufficiently large leakage reactance to affect the results, when pure resistances were used to represent the compliance of members. It is not at all necessary that there be pure resistances; in fact, any sort of impedance may be used, provided only that the phase angle of each impedance be the same. Accordingly, each branch was made up of a resistance plus an inductance, and the latter were chosen so that,

FIG. 4.



Vertical.

Circuit for pin-connected truss problem.
Resistances equal (Length/area) ohms.
Reactances included in all members to make ratio of resistance to reactance constant; leakage reactances of transformers the determining factor.
Circuits coupled by transformers indicated by dotted lines.

together with the leakage inductance of the transformers, they produced equal impedance angles. This procedure is, of course, unduly laborious for rapid work. Accordingly, in any permanent arrangement, the transformers should be so designed that their leakage reactances are negligible, or else condensers should be permanently connected to each transformer so as to compensate at all times for the effect of leakage reactance.[4]

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[4] Mallock, loc. cit., has developed an ingenious and satisfactory method for avoiding difficulty due to imperfect transformer action which may be extended for use in cases of this sort.

TABLE I.

Loading and Stresses in Thousands of Pounds in the Two Indeterminate Panels of Fig. 1.

Loading.	300 lbs. at *A*.			300 lbs. at *B*.			150 at each of *C* and *D*.		
Member.	Calc.	Meas.	Per Cent. Error.	Calc.	Meas.	Per Cent. Error.	Calc.	Meas.	Per Cent. Error.
a	247.	247.	—	312.	312.5	—	147.7	142.9	0.1
b	141.	141.	—	310.3	309.	0.4	232.2	229.5	1.0
2	173.	174.	0.5	228.	228.	—	127.3	126.8	0.5
3	159.	158.	0.6	290.	288.5	0.5	217.8	215.2	1.2
T_1	233.	229.	1.7	48.2	49.0	1.8	37.3	37.2	0.2
P_2	28.2	28.9	2.5	97.8	99.0	1.2	15.0	14.6	2.7
P_{20}	21.2	20.9	1.3	70.3	70.0	0.5	37.8	38.0	0.5
T_2	9.8	10.06	3.0	186.	187.	0.5	74.6	74.6	—
P_x	94.7	95.9	1.2	68.2	67.4	1.0	52.7	51.6	2.0
P_l	54.9	57.0	3.5	70.6	70.8	0.3	73.8	73.7	—
P_r	30.0	30.2	0.6	99.4	98.8	0.5	53.5	53.6	—

This problem was worked out using ordinary meters for measurement. As the insertion of the ammeter appreciably affected the circuit, a compensation for the ammeter resistance was made by changing the corresponding branch resistance each time the meter was inserted in such a way as to hold the total resistance constant. Again this is too slow a procedure for permanent use, and a thermionic-tube ammeter constructed so that it could be inserted at will in any part of the network without disturbing its performance would be much better. Such a meter is readily designed and was used in later work.

The results check computation sufficiently closely for many engineering purposes. It will be observed that the percentage error tends to be larger in members with low stresses.

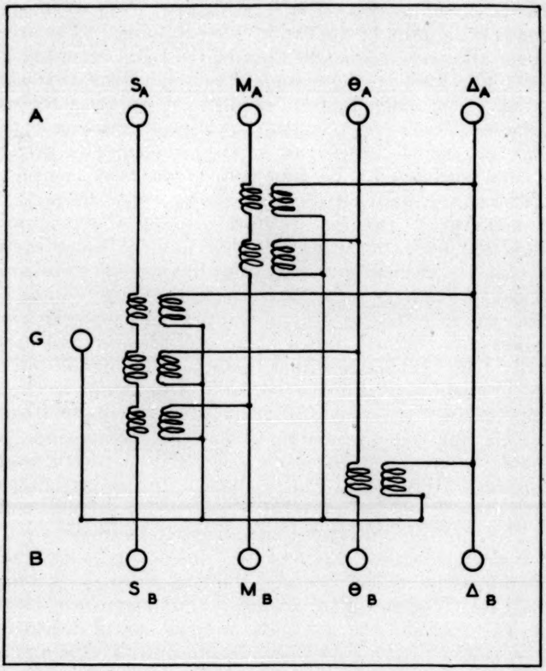
The extension to more complicated, pin-connected, indeterminate structures can now be made without difficulty. Each inclined member requires two adjustable resistances and one transformer in order to represent it, and each other member requires one resistance. Experience with the network analyzer gives a basis for estimation of the time necessary to make solutions, provided sufficient suitable apparatus were conveniently available for the purpose. Consider as an example a structure, of the type now under consideration, having 100 members. To set up and adjust the corresponding network would require perhaps two hours. Any usual system of loads could then be applied in a few minutes. The stresses all over the structure could then be read and recorded in an hour. The limit to the complexity of structure that can be treated is set only by the number of electrical elements available.

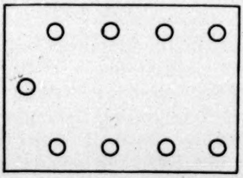
So far only the static case of the pin-connected structure has been considered. We now turn to the more complicated problem of the static stresses in a rigidly connected structure. In a structure of this sort we have to consider moments and shears, and angles of members become equally important with deflections. We will treat only cases in which all members are vertical or horizontal, and in which the longitudinal compliance of members is negligible by comparison with their flexibility as beams. When there are diagonal braces it is usually true that longitudinal rigidity will control, and that moments can then be neglected, so that we revert to the preceding cases. In some few structures there are diagonal members and yet the reactions due to bending and longitudinal strain are of the same order of magnitude and an extension to these cases can be made. In the present paper the treatment will be limited to the structure, similar to that of a frame of a building, without diagonal members.

A single member will first be considered, and then the interconnection of members. A single member is characterized by the shear in the member, the moments at the two ends, the angles of the two ends, and the lateral deflection of the two ends. Such a member is represented by the network of Fig. 5. All transformers are current transformers. The analogy is always with current; that is, with different conversion factors in each case, current gives shear, moment, angle or deflection.

Let moments acting on a member be positive if acting in a clockwise direction; positive angle be in a clockwise direction; positive relative deflection in a member correspond to a clockwise rotation of the line joining the ends of the member; and positive shear produce positive deflection. Then positive shear may be represented by current flowing into the *A* end of the member and out of the *B* end. Positive moments at either

Fig. 5.


S_A
M_A
Θ_A
Δ_A
A
G
B
S_B
M_B
Θ_B
Δ_B



end are represented by current flowing into the member. Positive angle is given by current flowing in at the A end and out at the B end. Current flowing in at the A end and out at the B end represents the absolute deflection of the A and B ends respectively, so that the relative deflection in the member is represented by the difference between these two currents.

If the weight of the members be neglected and the loads including wind loading be treated as if applied at panel points only, then the equations of an individual member may be written:

$$M_A + M_B + SL = 0$$

$$\theta_A = \theta_B + M_A(L/EI) + S(L^2/2EI)$$

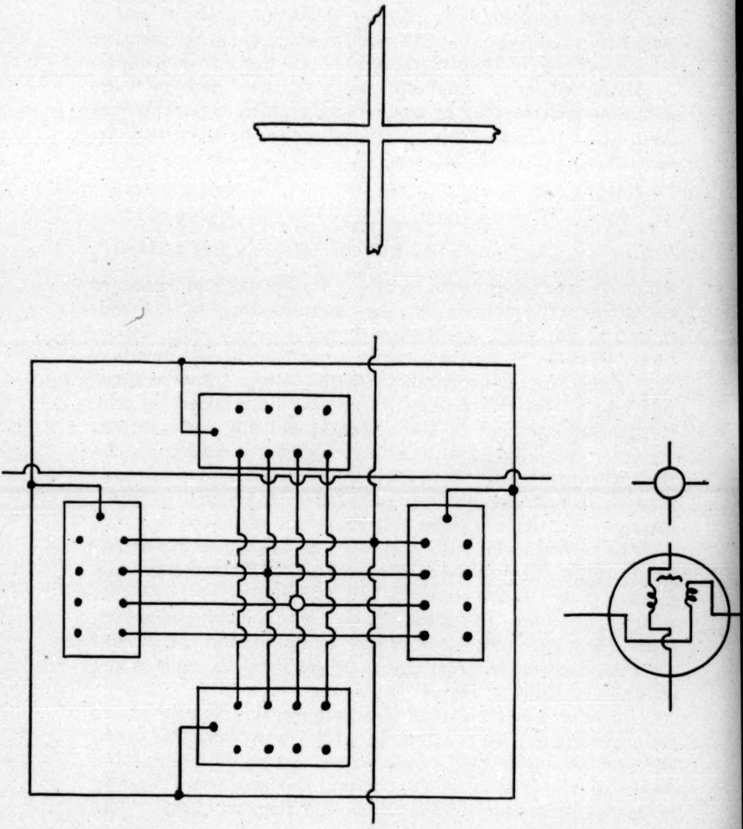
$$\Delta_A - \Delta_B = \theta_B + M_A(L^2/2EI) + S(L^3/3EI),$$

where S is the shear in the member, M_A the moment acting on the A end of the member, M_B the moment acting on the B end, θ_A and θ_B the angle of rotation of the A and B ends respectively, and $\Delta_A - \Delta_B$ the relative deflection in the member. The transformer connections indicated in Fig. 5 impose these relations. The transformer ratios are determined by the length and stiffness of the member and the scale factors chosen. Actually, as far as a single member is concerned, the the transformer ratios may all be 1 : 1 except for a single unit if scale factors are properly selected. It remains to interconnect such units in order to represent a structure.

The terminals of Fig. 5 are for use in connecting to adjacent units, G being a common terminal. Thus, if terminals marked G and θ_B are connected to terminals G' and θ_A' of an adjacent network, the value of the current leaving θ_B represents the angle of the member here represented at end B, and the interconnection forces this to be equal to the angle of the adjacent member at end A, and so on.

Consider four structural members meeting at a point, as shown in Fig. 6. In the diagram of the network of this figure the unit shown in Fig. 5 is indicated simply by the symbol shown at the bottom of that figure, the unlabelled binding posts corresponding to those of the full diagram above. The interconnections are such as to preserve the following relations between the members meeting at the panel point. First the sum of the moments is made zero, by joining the four corre-

FIG. 6.

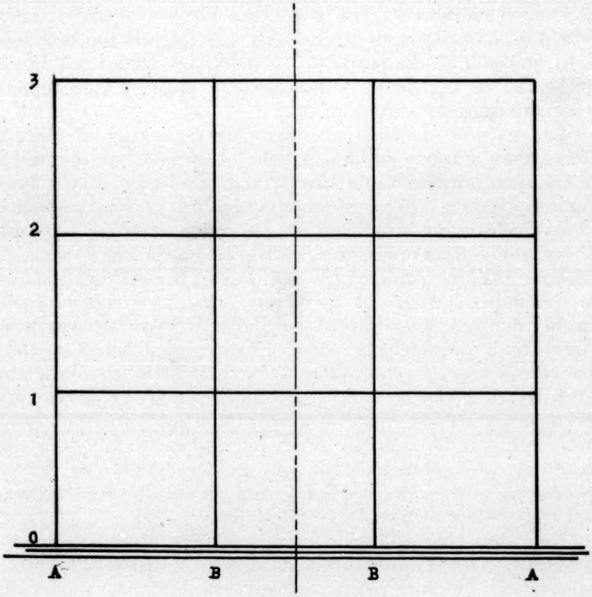


sponding circuits. Second, by the use of a 1 : 1 transformer, the angles of all members at the panel point are made equal. This transformer is indicated symbolically by a circle, the actual connection being as shown at the right. Third, the deflections of adjoining ends of vertical members are made equal by series connection. The same is done for adjoining horizontal members. The two pairs are not equated, however, for the deflections are in each case lateral, and hence at right angles and independent. Finally, the shears are interconnected in a manner which will be clear in a complete structure representation.

Let us now consider the complete structure of Fig. 7. This shows a frame of nine panels, or twenty-one members, acted upon by horizontal forces, and connected at the base to a foundation. The problem may be that of wind pressures on a steel frame building. In the corresponding network shown in Fig. 8 there is a unit, such as shown in Fig. 5, for each member. The complete network is complicated, but it must be remembered that the formal treatment of this problem would involve the solution of a large number of algebraic equations if no algebraic reductions were employed so that the complexity of the network is forced by the inherent difficulty of the problem being attacked. As a matter of fact the network can be simplified by taking advantage of symmetry, thus making it necessary to represent only half the structure, and equations may be greatly combined before proceeding to the electrical set-up, but in the present explanation it is clearer to use the full diagram.

Note first that wherever members meet at a panel point the sum of the moments is made zero by complete interconnection. Second, wherever members meet, the angles are made equal, by series connection in the case of two members, and by transformer in the case of three and four. Third, where two vertical members meet, the lateral deflections are made equal by series connection. However, the lateral deflections of horizontal members must be zero, so the corresponding circuits of members 1–9 are left open. The lateral deflections of all vertical members are made equal at each floor level by transformer connections. Also the deflection, as well as the angles, of the lower ends of members 10, 13, 16, 19, are held at zero by the foundation, so these terminals are also left open. Finally, let us trace the shears. The applied loads are represented by adjustable sources of alternating current F_1, F_2 and F_3. These supply currents are held strictly in phase. Similarly, the currents which appear at R_1, R_2, R_3, and R_4 represent the reactions which appear at the foundation. The load F_1 is equal to the sum of the shears in members 12, 15, 18, 21. The five corresponding connections

Fig. 7.



Continuous frame building.

For each member:
$E = 3 \times 10^7$ lbs./in.^{2}
$I = 1000$ in.^{4}
$l = 100$ inches.

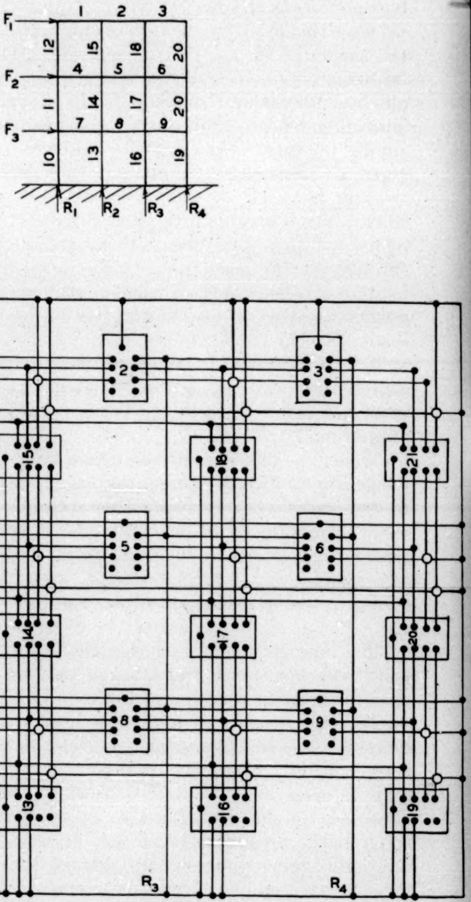
are brought to a knot point to force this condition. Similarly for reaction R_1 and the shears in 1, 4, 7 and also for R_4. Next we have the fact that the sum of shears in 11, 14, 17, 20, minus the shears in 12, 15, 18, 21 equals F_2. This is forced by the interconnection shown, in which the connections representing all these shears and that for F_2 are brought to a knot point. The other load F_3, and the reactions R_2 and R_3 are treated in similar manner. Care must be taken, of course, to maintain algebraic signs correct in making the connections.

The network is now completely constrained, and the constraints correspond to those in the structure. Measurements will now give shears, moments, angles, and deflections throughout the structure. Moreover, any other system of loading can be examined without making new network interconnections by simply altering the currents representing the loads. If the loads are not in the plane shown they can be split into components which can be applied to the networks representing two sections of the structure, and they will act independently. Usually only one component requires examination.

This type of structure requires a large number of current-transformers for its representation. It was hence important to determine whether reasonable accuracy could be obtained with transformers of an inexpensive sort. The effect of transformer errors on the final result cannot be predicted in any simple way by computation, so experimentation in a typical problem was resorted to in order to obtain an indication of what might reasonably be expected.

The moments, shears, angles, and deflections resulting from wind load on a simple frame structure were determined. The structure chosen was that of Fig. 7. The loading of 1000 lbs. applied horizontally at each floor level was assumed. Symmetry was taken advantage of in order to reduce the network complication. Members representing half the center bents may be used, and the conditions at the center line imposed. This was simplified still further by recognizing the fact that so far as the remainder of the structure is concerned, only the relation between moments and angular rotation at the ends of these bents need be taken into account. A single transformer is sufficient to impose this condition. Between members, the

Fig. 8.


F1
F2
F3
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21
R1
R2
R3
R4

boundary conditions are imposed by the proper connections, as treated above. The resulting network is shown in Fig. 9.

The design of the transformers used was based upon the data for Hypernik given by Yensen.[5] The data on various thicknesses of laminations were extrapolated, which may account for some of the difficulty later encountered. The loss component of exciting current at sixty cycles per second was considered negligible for the thickness of laminations used (0.005″). Subsequent tests indicated that this was not the case, although the fault may have been with the treatment given the laminations. However, fairly satisfactory transformers were obtained. The cores were made up of continuous annular laminations $2\frac{1}{16}''$ outside diameter, $1\frac{3}{4}''$ inside diameter, .005″ thick, annealed and lacquered. Forty-five laminations were used, giving a cross section of .24 square centimeter.

The basic winding was 222 turns of No. 19 B. & S., enameled and cotton covered, doubled, for both primary and secondary. The coil was put on by hand, carrying the four strands through together, both to insure a one-one ratio and to produce a minimum of leakage reactance.

Testing the ratio of transformation of various units and under various conditions gave an average error of about 1.5 per cent. maximum for a load equivalent to five times the resistance of a single transformer, over the range of currents for which the transformers were designed, and at 60 cycles per second. This is none too good and can certainly be improved upon without increasing costs in later designing.

The object of the tests, however, was to determine the overall errors caused by imperfect transformer behavior, and it was hence an advantage, rather than otherwise, to utilize transformers somewhat less perfect than could be produced at low cost.

A set of experiments at 60 cycles per second soon showed that the transformer behavior noted above is not nearly good enough. The actual network is so complicated that it is not easy to visualize the conditions under which individual trans-

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[5] T. D. Yensen, "Permeability of Hypernik Reaches 167,000"; *El. Jl.*, **28**, No. 6, June 1931.

FIG. 9.

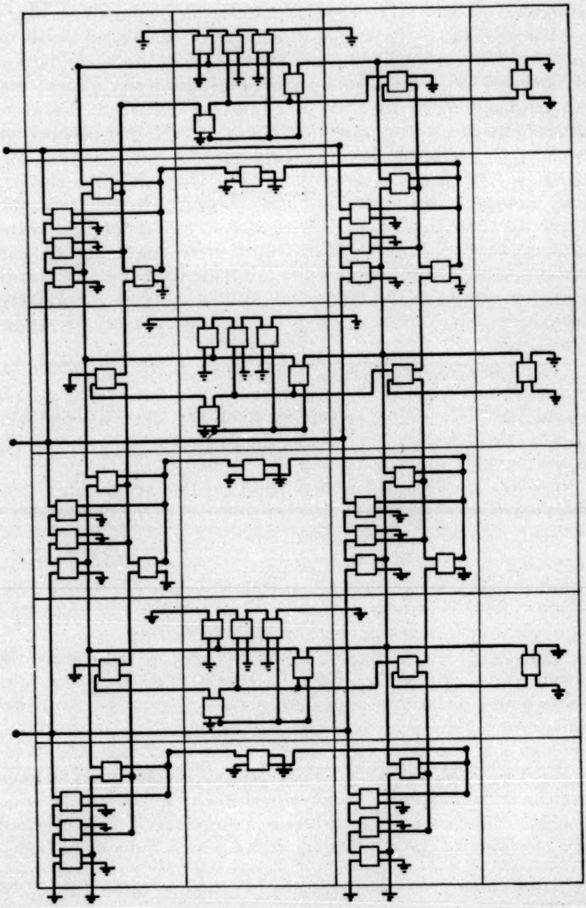

TABLE II.

Results, Continuous Frame Structure.

Item.	Value.		Per Cent. Error.
	Calculated.	Measured.	
SA10	667 lbs.	655 lbs.	−1.9
SB10	833	835	0.2
SA21	374	366	−2.2
SB21	626	625	—
SA32	183	165	−10
SB32	305	336	10
S3AB	219	210	−4.1
S2AB	525	490	−6.7
S1AB	774	718	−7.2
M1AB	415×10^2 in. lbs.	390×10^2 in. lbs.	−6
MA12	159	145	−9
MA10	255	234	−8
M2AB	278	258	−7
MA23	64	45	−30
MA21	214	210	−2
MA32	119	107	−10
M3AB	119	107	−10
M3BB	84	90	7
M3BA	99	94	−5
MB32	182	205	13
M2BB	218	242	11
MB21	328	331	1
MB23	137	131	−4
M2BA	247	228	−8
MB10	366	360	−2
MB12	299	300	—
M1BB	305	336	10
M1BA	360	328	−9
D1	.00316 in.	.00313 in.	−1
D2	.00319	.00324	1.5
D3	.00172	.00167	−3
θA1	261×10^{-7} radian	267×10^{-7} radian	2.2
θA2	170	166	−2.4
θA3	72	67	−7
θB3	46	46.5	1
θB2	121	127	5
θB1	169	176	4

formers operate, but in some cases they are in effect bucking each other. The net result is that, in order to obtain good overall precision, the individual transformer behavior must be very good indeed.

In order to make the next series of tests, however, it was not necessary to build new transformers. Tests at 500 cycles per second showed a greatly improved performance of the transformers already available, the error in ratio being about one-third of what it was at 60 cycles per second. The relations of individual members, when separately examined, checked within one per cent. Moreover, with the precautions noted below, the tests on the entire network now yielded the results of Table II, which are probably sufficiently good for practical purposes. It should be noted that the accuracy is best on the numbers having large stresses. Very large per centage errors go with small values. Thus, the smallest moment is 30 per cent. in error. It thus appears that a good indication has been obtained of the transformer performance necessary, and this performance can readily be obtained in later designs at either 60 or 500 cycles per second and with small units of low cost. This can be done—in fact, apparently with a considerable margin—by making sure that losses are as low as obtainable by use of nickel-iron magnetic materials, and by either designing for low total excitation or by cancelling the magnetizing component by the use of condensers.

In the tests a number of precautions had to be taken to ensure accuracy. In order to avoid unduly disturbing the network upon the insertion of the ammeter, a low resistance shunt was utilized with a thermionic tube amplifier. This is a satisfactory procedure when provision is made for frequent calibration. Since the resistances everywhere in the network must be low, great care had to be taken to ensure low resistance joints and connections. In any permanent arrangement, this point will require close attention.

In a flexible network, arranged to be readily connected at will to represent various structures, it will be advisable to provide means whereby the ratios of transformers may be rapidly checked in service. This is because of the fact that it is almost impossible, by a mere inspection of the circuit diagram, to determine whether the conditions of operation of every transformer are within the range for which it was designed.[6] Some, at least, of the transformers should be provided with taps so that the ratio of current may be readily corrected if it departs seriously from normal. This procedure was carried through somewhat laboriously in the absence of special provisions, in the tests here reported. In the case of three key transformers, the ratio was found to depart notably, and was corrected by adding one or two turns. With complete equipment this procedure will occupy only a short time and will be a necessary precaution.

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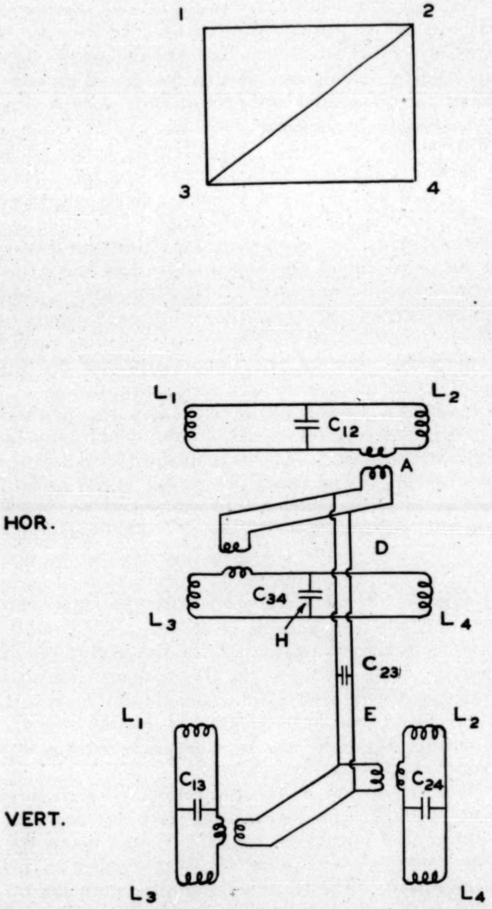
[6] Mallock, loc. cit., developed a method for automatic correction of potential transformers. This can be altered to apply to current-transformers as here used.

This completes the treatment of structures in the static state. The sets of equations thus far involved have been algebraic. It is evident that the network methods employed may also be used for evaluating determinants. For rapid use in structural engineering, however, it appears to be preferable to adhere to the procedure of passing directly from the structure to its corresponding network. This eliminates a considerable amount of algebraic work and avoids some danger of error. This is accomplished at the expense of involving rather complicated networks, but as the units employed are inexpensive this does not appear to be a serious limitation.

There is no reason except complexity why the method cannot be extended to continuous structures, which may be essentially three-dimensional. In the analysis of such a structure as a concrete dam, the accuracy obtainable would depend upon the number of units utilized and the extent to which transformer action approached the ideal. The procedure would be to arbitrarily divide the structure into units, not necessarily cubical, and to represent the interaction of each with all its neighbors in much the same way that has been described for the members of a frame structure. The complication would be very large if the size of the units were taken reasonably small. Yet, in view of the serious difficulty involved in analysis of this sort of structure by any means, it is desirable that the method here outlined be further investigated in this connection than has been possible during the study which has led up to the present paper.

The next problem is that of the pin-connected structure under transient loading. The governing laws are now expressible by differential equations, and it becomes necessary to represent the masses present in the structure as well as the compliance of members. The frictional damping may also be represented, although in a structure it is usually small, and

FIG. 10.


1
2
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L_1
L_2
C_{12}
A
HOR.
D
C_{34}
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C_{23}
E
L_1
L_2
C_{13}
C_{24}
VERT.
L_3
L_4

often highly inestimable. The masses will be considered concentrated at the panel points.

There are two electrical analogues which may be used and the more readily visualized of these will be considered first. In this, masses will be represented by inductances, and the compliance of members by condensers. Mechanical friction, if taken into account, is represented by electrical resistance.

A very simple structure is shown, for illustration, in Fig. 10. We make two networks as before. Each mass is represented in both networks by an inductance L_n which is proportional to M_n, the mass at the corresponding panel point in the structure. Any desired proportionality factor may be used. In the horizontal network we connect in series any two masses which in the structure are connected by a horizontal member, and similarly in the vertical network. Across this interconnection we connect a condenser C_{mn} representing the compliance of the connecting member. Again the proportionality factor between capacitance and compliance may be chosen at will. For an inclined member we interconnect corresponding masses in both networks, using transformers of ratios chosen as indicated above. Across both of these interconnections we connect a single condenser representing, to the same scale as for the condensers above, the compliance of the inclined member.

The analogy is as follows:

In the Structure.		In the Network.	
Mass.	M	Inductance.	L
Resilience.	S	Capacitance	C
Velocity.	V	Current. . . .	I in a coil
Displacement.	l	Charge.	Q through a coil
Stress.	F	Voltage. . . .	V on a condenser

Horizontal velocities, displacements, and stresses appear represented in a horizontal network, and similarly for the vertical network.

Notice that the interconnection is such that the charge appearing on a condenser representing the compliance of a horizontal member is proportional to the difference in the horizontal displacements of the panel points to which it is connected, and similarly for the vertical members. For an inclined member the relationship is as follows: Consider the transformer A, to be explicit. The charge passing through the primary is proportional to the horizontal displacement of point 2 of the network. The charge passing through the secondary is hence, in accordance with the transformer ratio, proportional to the change in length of member 2–3 produced by such a displacement acting alone. Thus the charge passing the leads at point D is proportional to the change in length produced by the difference of the horizontal displacement of points 2 and 3. Similarly the charge passing E is proportional to the change in length produced by vertical displacements. The charge appearing on condenser C_{23} is hence proportional to the net change in length of member 2–3. All static relationships are hence maintained, for the voltage across a condenser is equal to the quotient of charge and capacity, and the stress appearing in a member is equal to the quotient of change of length and resiliency. It remains only to examine dynamic relationships, which is a simple matter. The voltage across any given condenser is applied to both of the inductances to which it is connected and tends to produce a change of current in them. The stress in a given member acts on both masses with which it connects, and tends to accelerate them. We have also

$$L\frac{dI}{dt} = V$$

and

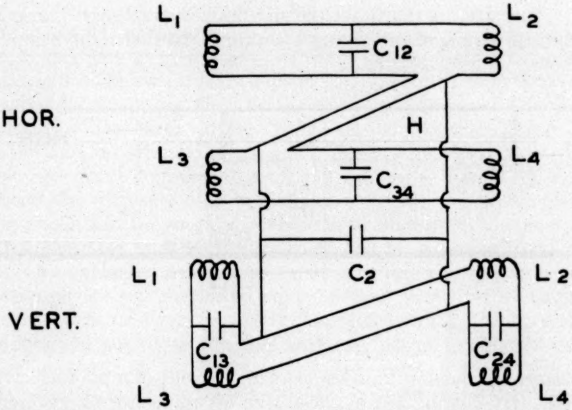
$$M\frac{dV}{dt} = F.$$

The same set of differential equations hence governs both the behavior of the network and the motion of the structure. The analogy is hence complete.

The network may be simplified by altering scale factors in order to obtain unity-ratio transformers, and by omitting transformers in cases where it is not necessary to retain independence of circuits. Thus, if the structure of Fig. 10 is square, the network can be reduced to the simple form shown in Fig. 11.

Since stresses are represented by voltages the sudden application of a load is represented by the sudden application of a constant potential. Thus the sudden application of equal opposing horizontal forces to points 3 and 4 of the structure would be represented by the sudden connection of a battery in series with the circuit at point *H* of Fig. 10 or Fig. 11. Measurements are now made by oscillograph, preferably by aid of a thermionic tube amplifier in order not to disturb the network. The oscillograms give the time variation of velocity, and hence, by integration, of displacement, or of stress. The proportionality factor between the time scale for the oscillogram and for the structure is readily evaluated. The conditions for proper transformer action are simple, as the effect of leakage reactance may be offset by adjusting external inductances.

FIG. 11.

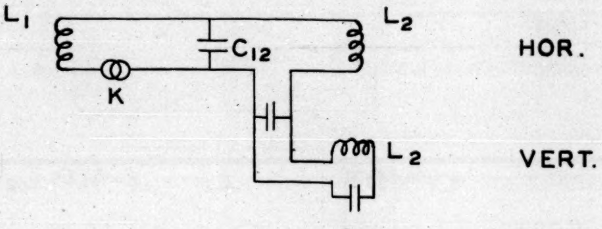


Cases will often occur where certain panel points are fixed, as when they are anchored to the foundation. There can then be no motion of these points under ordinary conditions and this is provided for by opening the circuit of the corresponding inductances. This simplifies the network at these points. Thus, if points 3 and 4 of Fig. 10 are anchored to the foundation, the circuit reduces to that of Fig. 12. In this diagram is shown an alternator at *K*, representing a sinusoidally variable force applied horizontally at mass 1, such as might be due to a varying wind. The vertical motion of mass 1 is omitted in the circuit as there is no cause present to produce such a motion.

Now generally variable forces may be applied just as well as simple ones. For example, we have the important problem of the stresses produced when a train runs over a bridge. To simulate this problem we have to apply to a number of panel points a load which varies in a known manner with the time. It is hence necessary to produce and apply a set of voltages having a prescribed time variation. There are numerous ways of accomplishing this.

One way, perhaps not the simplest, is as follows: Using an optical arrangement giving a uniform parallel light beam, a screen is moved at uniform velocity in front of a photoelectric cell. By cutting out of the screen an aperature to represent the prescribed function, the current in the photocell can be made to have the desired time variation. By the use of thermionic-tube amplifiers, this can be converted to a voltage of suitable magnitude to be applied to the network. Using a number of photo-cells the voltages for successive panel points can be generated successively, with proper overlap in time. Moving the screen in front of the row of photo-cells is then a very analogous procedure to running the train across the bridge. The examination of the structure for different kinds and loading of trains then involves merely the cutting out of a set of screens of proper apertures. The effect of a change in

FIG. 12.



speed of the train is completely simulated by changing correspondingly the speed at which the screen is moved. A very thorough-going examination of a structure is hence possible. If the mass of the train is comparable with the mass of the structure, it is apparently possible to include its effect, by an extension of the method which needs more discussion than can be given in the present memorandum.

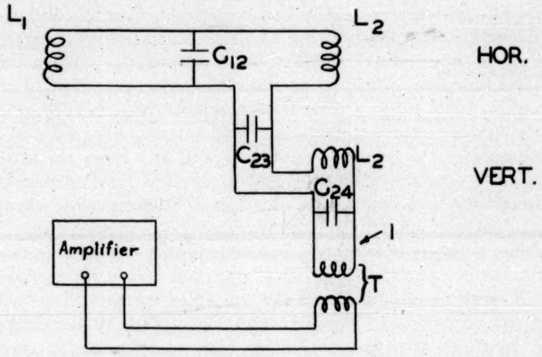
Now there is another very important problem of transient stresses, namely the problem of the behavior of a structure under earthquake conditions. In this problem, the panel points of the structure which are connected to the foundation are given a forced motion; the nature of which is known roughly at present, and will be known better in the future, as the result of seismographic investigation. Electrically, this problem involves introducing at these panel points a current having a time variation which is in accordance with a prescribed function, obtained as the observed component of the velocity of the earth during typical earthquake disturbances. If the complete three dimensional problem is being considered, there are three component networks, and into those are introduced the corresponding horizontal, vertical, and transverse components of the motion. This can be done simultaneously, or successively and the results combined by superposition.

The method of producing a current having the desired time variation is very similar to that outlined above for variable forces, with an alteration of the amplifier which will be well understood by those familiar with the use of such devices. The method of introduction is also clear without great explanation. In Fig. 13 is shown the connection for applying to the structure of Fig. 12 a horizontal motion of the supports of known form. This is done by introducing into the network through transformer T a current whose time variation is a replica of the known motion. Oscillography is used in this case as well, of course, in order to examine stresses and deflections.

Now the above treatment of a determinate pin-connected structure under transient conditions applies without any additional features to the problem of the indeterminate pin-connected structure under transient conditions, and hence to a large class of important practical problems. The compliance of members has already been introduced, and when this is properly cared for there is no essential difference between the determinate and indeterminate structures. A further section on the indeterminate pin-connected structure is not necessary. It is hardly necessary to give examples of more complicated structures than are given in the examples, as the more complicated structure simply involves the interconnection of more electrical elements, but no new principles.

The mathematical treatment of the transient behavior of structures is identical with that of the electrical networks. All of the considerable literature developed by electrical engineers is directly applicable to the structural problem. In considering the characteristics of structures from the point of view of response to transient impressed forces, it is convenient to analyze first for the response to some standard impulse, and then to use the principle of superposition to investigate the response to forces of various time variations.[7] The use of the network in studying the transient behavior of structures may hence be limited to an investigation of the response under a

FIG. 13.



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[7] A recent treatment of this subject appears in "Calculation of the Stresses Occurring in a Building during Earthquakes" by M. Biot, presented before the A. S. M. E. at New Haven, June, 1932. See also "Operational Circuit Analysis," loc. cit.

standard impulse. From these one may proceed either by analysis or by further measurement. The major difficulty, that of obtaining the standard response, which may readily involve a prohibitive amount of labor from a strictly analytical standpoint, appears to be best obtained by measurement on the electrical analogue.

There is an alternative analogy which may sometimes be preferable in studying pin-connected structures under transient conditions. This is obtained by interchanging the rôle of condensers and inductances in the representation above. The analogy then is

In the Structure.		In the Network.	
Mass	M	Capacitance	C
Resilience	S	Inductance	L
Velocity	v	Voltage	E on a condenser
Displacement	l	$\int E\,dt$	
Stress	F	Current I through an inductance	

The arrangement for the structure of Fig. 10 becomes that of Fig. 14. The static analogy is preserved by connections similar to those of Fig. 10. It is unnecessary to go through the complete treatment. The analogy follows because of the relations.

$$\frac{dE}{dt} = \frac{I}{C}$$

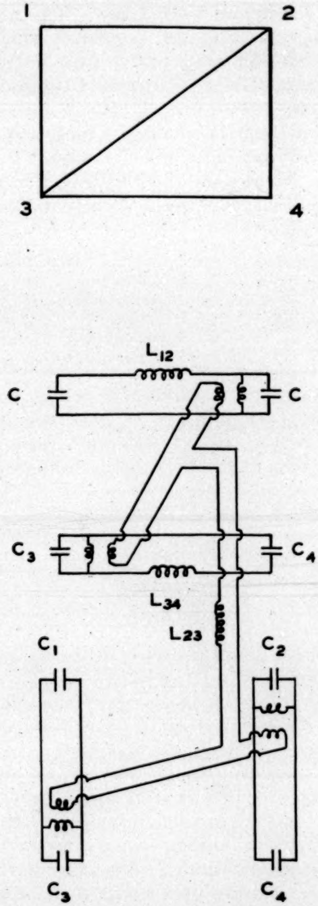
and

$$I = \int \frac{Edt}{L},$$

which hold for a simple inductance-capacitance circuit. Potential transformers now replace current transformers. Applied loads become applied currents. Velocities of the foundations are represented by applied voltages. There are certain advantages of this arrangement. In general any circuit proposed for purposes of this sort, involving coils and condensers, may be reciprocated in this manner.

The analogy for the transient case of the frame structure may be built up along similar lines. Unfortunately, it is likely to be seriously complex. The case of the frame of a building, however, admits of a great deal of simplification, since the interesting motions are usually horizontal, and the

FIG. 14.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2
3
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L_{12}
C
C
C_3
C_4
L_{34}
L_{23}
C_1
C_2
C_3
C_4

entire load on a floor may be considered concentrated. The problem thus is reduced to that of determining the elastic restraints among the various floor levels, of constructing an electric network embodying capacitances to represent the masses, and measuring the response to applied forces.

As an example of this procedure, a brief study was made of the frame structure used for static study above. The restraints were calculated and are also readily obtainable from the static study. In order to form an estimate of the comparative labor involved, a check was made of static relationships by measurements on a mechanical model. This was built out of drill rod, and the restraints were obtained by measurements of this, using a micrometer eye-piece in a microscope to measure deflections. The various methods checked within about five per cent. Undoubtedly, if only a single structure were to be analyzed, the use of a mechanical model offers certain advantages. The use of the network for this purpose has its principal advantage when many structures are to be treated. It also gives directly by measurement the moments, angles, and shears, which are very hard to measure on a model.

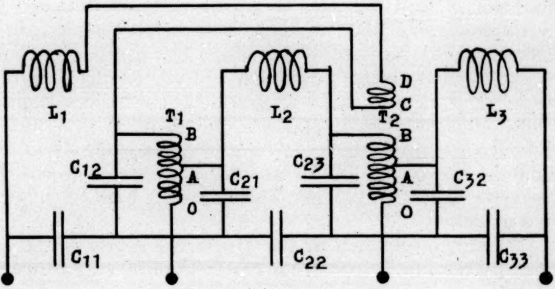
The circuit representing the structure is shown in Fig. 15. The equations to be satisfied in the mechanical structure are:

$$F_1 = S_{11}D_1 + S_{12}D_2 + S_{13}D_3$$
$$F_2 = S_{21}D_1 + S_{22}D_2 + S_{23}D_3$$
$$F_3 = S_{31}D_1 + S_{32}D_2 + S_{33}D_3.$$

The system is considered closed; that is, the reaction of the applied forces appears at the base. The D's are deflections; the F's the applied forces. From static measurements of a model, or from measurements of an equivalent electrical network, or from direct numberical computation, a group of deflections corresponding to arbitrary applied forces can be determined. From these measurements the S's (stiffness coefficients) can be calculated. This is not a case of solving for nine unkowns from three equations, as a number of independent equations may be set up in terms of deflections resulting from a variety of applied forces. As the equations are written, the terms S_{11}, S_{22}, S_{33} correspond to the total stiffness in their respective meshes, and not the stiffness in that mesh which is not included in other meshes. Note this difference in terminology from the C_{11}, C_{22}, C_{33} of Fig. 15. In setting up the electrical analogue, S is proportional to $1/C$, and the mass M proportional to L.

Note that to supply the term S_{13} mutual inductance must be relied upon. This is necessary to provide the required isolation of the intermediate mesh. It became apparent, in solving for the various capacitances, that mutual inductances would be necessary in other places. Otherwise it appears that the sum of the mutual stiffnesses between a given mesh and the remainder of the system is greater than the desired self-stiffness. This would require for its realization the introduction of negative capacitances, which are rather difficult to realize physically, although not impossible.

FIG. 15.



Transient loading of continuous structure.

A	B	C	D
$L1$ 19.5 mh.	$C11$ 106 mfd.		Transformer ratios:
$L2$ 19.5 mh.	12 12.7		
$L3$ 9.75 mh.	21 47.3		$T1$ $BO : AO$ = 1.80
	22 378		$T2$ $BO : AO$ = 1.45
	23 18.2		$DC : AO$ = .386
	32 37.8		
	33 558		

1 slug = 6.27×10^{-7} henries,
1 ft./lb. = 635 farads,
1 second = 0.02 second.

Solving for the stiffness coefficients, from the observed deflections, gave the following results:

*S*11	2.68×10^6 lbs./inch.
22	2.16
33	.795
12	1.465
13	−.268
23	1.01

Floor loads consistent with the strength of the building were assumed, namely 10^6 pounds at the first and second floors, and 0.5×10^6 pounds on the top.

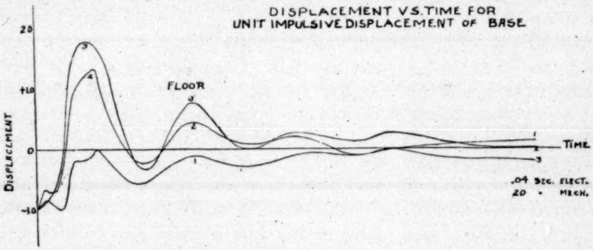
The transformers used could bear considerable improvement if designed for this purpose. Ideal transformers are needed. The approach to this consists of obtaining the greatest possible difference between open and short circuit impedance. The difficulty of realizing this is increased by the fact that the transformer must be "ideal" over a fairly wide range of frequencies, if it is to be of use in a transient problem. At 60 cycles, which was chosen as the mean of the frequency range considered important, the leakage reactance appeared to be less than five per cent. of the reactance used in the various meshes to represent the masses. The effect of the transformers was minimized by using them as auto transformers where possible, and introducing them between condensers, using ratios approximately equal to the ratio of impedance desired on the two sides. Measurements of the elements of the condensers, separately and combined with the transformers, checked within about two per cent.

Scales were so chosen that 0.3 to 3.0 cycles per second in the mechanical structure corresponded to 15 to 150 c.p.s. in the electrical network. The relative magnitudes of inductance and capacitance were chosen to fit in conveniently with the available transformers. The scales, and the magnitudes of the electrical elements, are shown in Fig. 15.

An initial transient displacement of the base relative to the rest of the structure corresponds to an initial charge introduced into all meshes. This is accomplished by discharging a condenser from a high potential through the network, from A to D. The potential across the condensers C_{11}, C_{22}, C_{33} will be proportional to the displacements of the respective floors, to the proper scale. Oscillograms of these potentials as a function of time were taken, for the case of an initial impulsive displacement of the base, and for a surge displacement. This latter was obtained by the discharge of a condenser through an inductance and resistance. The curves have been plotted to the same scale, both for time and displacement, for convenience.

Nothing has been said so far, about damping. Little is known about it in the usual mechanical structure, and if and when known it can readily be adjusted in the electrical circuit. In the absence of this knowledge, the electrical network contained arbitrary damping and the oscillograms are useful for indicating natural periods, and points of greatest stress for various types of impressed driving forces.

Fig. 16.



Variation of the electrical constants of the network with frequency and current might produce trouble, but it is thought that the values will remain constant within the allowable error, which at the present time is rather large. The system is extremely convenient to handle, in comparison with a mechanical model, and various types of transients can easily be impressed on the system, through the proper sort of driving source.

A typical oscillogram is reproduced in Fig. 16. This is presented, not because it indicates anything unusual, but simply as an example of the sort of result obtainable.

The networks which have been developed are not the only ones which may be used. Practical progress in extending our knowledge of the behavior of complex indeterminate structures in the static or transient case by this method will be possible only when special equipment is constructed especially for the purpose, for the conditions which must be met for satisfactory performance are unique. The experimental work here presented, obtained with equipment which was usually not especially adapted to the purpose, is hence preliminary; and it is reported primarily for the purpose of showing the nature of the apparatus necessary and the conditions to be met in its construction. It is believed as the result of this experience, that it is possible to considerably extend, by this method, the facility with which important structures may be analyzed.

In this problem, I have been greatly assisted by the criticism and suggestions of Mr. E. L. Rose, who worked out some of the more difficult circuits. Professor H. L. Hazen kindly aided in the transformer design. Mr. W. M. Hall collaborated with me in the experimental portion of the work. All of this help is greatly appreciated.

CAMBRIDGE, MASS.,
August 17, 1933.

Vibrated Concrete for Roads.—(U. S. Department of Agriculture Clip Sheet, No. 809.) According to a report by F. H. JACKSON AND W. F. KELLERMANN of the Bureau of Public Roads, concrete that is vibrated in the process of building highways can be much drier in consistency than when the ordinary method of road-surface finishing is used.

In tests to determine the effect of concrete vibration the following conclusions were drawn: (1) By the use of vibrating equipment it should be possible to place satisfactorily and finish considerably drier concrete than is possible with methods now in common use; (2) it should be possible to place and finish by vibration concrete having a minimum slump of 1 inch as compared to a minimum slump of 2½ inches for present practices; (3) depending upon the type of coarse aggregate used, vibration should permit a mix using from 0–2 to 0–6 sack of cement per cubic yard less than the base mix without impairing uniformity or flexural strength; (4) vibrations appear more effective when angular coarse aggregates are used instead of aggregates having rounded surfaces; (5) in general, vibration properly applied should result in an improvement of the quality of concrete pavements.

C.

Oregon Recovering from Effects of World War.—(U. S. Department of Agriculture Clip Sheet No. 811.) Grass from the Russian steppes has been brought to this country by the Department of Agriculture and is now available for restoring Oregon pastures and ranges broken and planted to wheat during the World War, but later abandoned to weeds and soil erosion. After the abandonment of war-time wheat prices all this ranch land of the Great Plains and Mountain States dropped out of cultivation and no effort was made to get back into grass again. As native grasses do not readily reestablish themselves, many years of profits from grazing were sacrificed to a few years of high returns from wheat.

Tests on American soil have shown that the creasted wheatgrass, native of the steppes, excels all other grasses in cold and drought resistance. It can stand temperatures as low as 50° F. below zero and it remains dormant, with no apparent loss in vigor, during the hot, dry midsummer. Its remarkable root system completely occupies the soil, preventing weeds and other plants from becoming established.

C.

ANALYSIS OF COSMIC RAY DEFLECTION EXPERIMENTS

The Magnetic Deflection Experiments of Curtiss and of Mott-Smith

BY

W. E. DANFORTH, JR.

ABSTRACT.

BARTOL RESEARCH FOUNDATION
Communication No. 85.

We have carried out a geometrical analysis which applies to that type of cosmic ray deflection experiment in which an extended region of magnetic field lies between the lower two of three or more Geiger-Mueller counters arranged in line for counting coincident discharges. It is apparent that charged particles of sufficiently low energy will be deviated away from the last counter and that the counting rate will therefore be reduced by application of the field. This paper presents a method for computing what proportion of electrons of a given energy will be eliminated by application of the field. The method is extended to include a constant loss of energy per unit path length as the particle traverses an iron core. The results of the experiments of Curtiss and of Mott-Smith are interpreted in the light of these calculations. Curtiss' result could be explained if all rays were electrons of 4×10^8 volts energy. One may conclude from his observation that if all the radiation consists of positive or negative electrons, the fraction between 2×10^7 volts and 1.5×10^8 volts is less than 30 per cent. of the total above 2×10^7, and that the fraction between 2×10^7 and 10^9 is greater than 30 per cent. A comparison of Curtiss' and Mott-Smith's experiments yields no reason for doubting the correctness of using the magnetic induction B when computing the deflection within iron. Nor does it necessarily sustain this procedure. An experiment by W. F. G. Swann and the writer is at present under way for the purpose of securing, if possible, more conclusive evidence on this point.

INTRODUCTION.

The corpuscular nature of at least a large fraction of observed cosmic radiation was demonstrated by Bothe and Kolhoerster [1] in 1929, and in 1930 Rossi [2] attempted to answer the next fundamental question, namely, are these corpuscles charged particles such as electrons? If so, they should be deflected by a magnetic field. Data regarding their penetrating power, however, indicated a very high energy so that a very strong magnetic field would be required. Realizing that such high fields are most easily attained within the iron core of a closed magnetic circuit, Rossi's experiments were designed to deflect the rays as they passed through the iron of his magnet. Another experiment using the same method for obtaining an intense field was performed by Mott-Smith.[3] In none of the experiments was an effect of the expected magnitude observed. Curtiss,[4] however, arranged his Geiger-Mueller counters so as to detect deflection in a magnetic field *in air* and did obtain a decisive positive result. An attempt to resolve this discrepancy raises numerous issues, the most fundamental being the following. *Is the true magnetic field acting on a charged particle passing through magnetized iron really the induction B?* Before going further into this question it seems desirable to discuss more critically than has been done heretofore the precise interpretation of the results obtained in these experiments.

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[1] Bothe and Kolhoerster, *Zeits. f. Phys.*, **56**, 751, 1929.

[2] Rossi, *Rend. Lincei.*, 11, 478, 1930. *Phys. Rev.*, **36**, 606, 1930. *Nature*, **128**, 1931.

The rigorous geometrical analysis of experiments of this type is usually most cumbersome. The method to be developed here applies only to those effects obtained with counters in line and with uniform magnetic field. We also restrict ourselves to those results which do not depend upon the sign of the charged particles. Our interpretation will, therefore, be unencumbered by our ignorance of the relative number with either sign. In this paper, therefore, we limit ourselves to a discussion of the experiment of Curtiss and to that case of the Mott-Smith experiment in which the counters were in line. Moreover, the treatment only takes account of that deviation produced by a uniform magnetic field and no attempt is made to formulate the effects of scattering within the iron or of the production of secondaries. One may therefore doubt its applicability to the Mott-Smith case. This matter will be discussed later. Throughout the paper we are adopting the hypothesis that the particles with which we have to deal are positive or negative electrons. The general method developed will, in a future paper, be extended to the somewhat more cumbersome analysis of an electrostatic deflection experiment being conducted by Dr. W. F. G. Swann and the writer, and to another magnetic experiment with iron which we have in progress.

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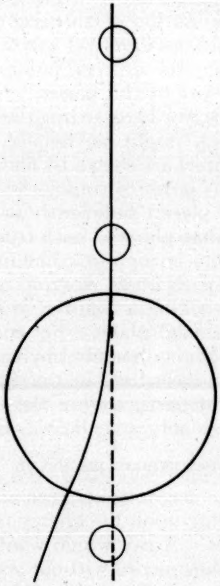
[3] Mott-Smith, *Phys. Rev.*, **35**, 1125, 1930. *Phys. Rev.*, 37, 1001, 1931. *Phys. Rev.*, **39**, 403, 1932.

[4] Curtiss, *Bur. Stands. J. of Res.*, **9**, 815, 1932.

The arrangement used by both Curtiss and Mott-Smith is shown schematically in Fig. 1. Three Geiger-Mueller counters are arranged in line for recording triple coincidences. Between the second and third counters is a region, shown by the large circle, in which a magnetic field perpendicular to the plane of the diagram can be produced. In Curtiss' apparatus this circle represents a cross section of his pole pieces. In Mott-Smith's arrangement it would be replaced by a rectangle representing a cross section of the core of his electromagnet. The essential feature of both experiments is the following.

FIG. 1.



The path of an electron which has passed through the two upper counters will be bent by the strong magnetic field so that the electron will not pass through the bottom counter. Thus if the field is strong enough, the triple coincidence counting rate should be zero with the field on. If, however, the kinetic energy of the particles be very high, application of the field may have little or no effect. The exact relation between the extent of the diminution of counting rate by the field and the energy of the particles involved was not formulated by the above investigators. Its determination for the two cases will constitute the work of this paper.

Some explanatory words regarding the schematic diagrams in Figs. 2, 3, and 4, might be helpful. Comparing them with Fig. 1, the counters are shown by lines representing traces of finite planes. To produce coincident discharges in three cylindrical counters placed sufficiently far apart, an electron must pass through that plane of each counter which includes the axis and which lies normal to a line joining the centers of the counters. The path of an electron will be called a ray. The phrase "a ray striking a counter" will mean an electron passing through this axial plane. For convenience the magnetic field will be taken as bounded by two parallel planes of infinite extent. The dash lines in the diagram are traces of these planes. This departure from the actual shape of the field region introduces only a negligible error.

PRELIMINARY DISCUSSION.

Application of the magnetic field can affect a ray in a number of ways, depending upon the energy of the ray and upon its initial coordinates. A ray which would pass through the three counters and thus record without the field, may or may not record in the presence of the field. Also a ray which would not record without the field, may or may not be bent into the last counter by the field and so made to record. Thus, although one's first reaction is that application of the field will reduce, if not eliminate, the counting rate, a class of rays does exist which tends to make the counting rate increase when the field is applied. The analysis of this paper takes this latter class into account but will show, in agreement with one's intuition, that application of the field will always decrease the counting rate no matter what energy distribution exists. Before proceeding with the quantitative work a brief contemplation of the different types of trajectories with which one has to deal should be of value.

FIG. 2.

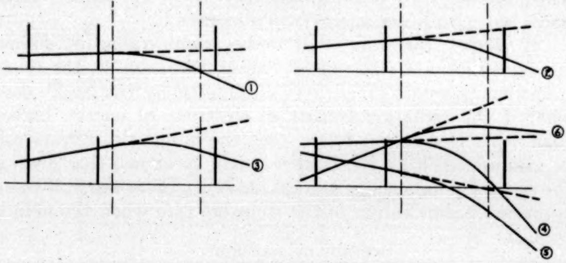
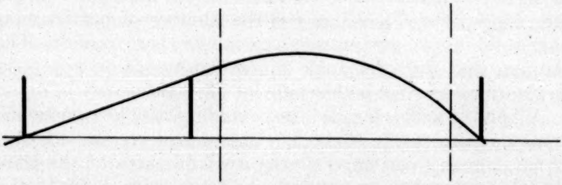


Fig. 2 shows a number of examples. Ray 1 would originally count but is bent away from the third counter by the field. Ray 2 is bent merely to a different place on the counter and so records with or without the field. Ray 3 would not count without the field but is bent by it into the third counter. This class 3 tends to make the number of counts *increase* when the field is applied. Ray 4 originally would not count and is bent past the third counter and hence records neither with the field on nor with it off. In addition to these is the trivial class represented by 5 and 6, which also record neither with the field on nor with it off.

FIG. 3.



In Fig. 3 a ray is shown inclined as far as possible above the third counter and bent by the field to the bottom edge of the counter. These conditions are sufficient to define uniquely its energy, which let us represent by V_1. A little reflection convinces one that this represents the lowest energy ray which can pass through all three counters with the field on. A ray of the same energy with any other initial coordinates will miss the third counter, and any ray of the same coordinates but with lower energy will also miss it.

It follows, therefore, that if the cosmic radiation should consist entirely of electrons of energy less than V_1 the triple coincidences would be entirely eliminated by the field. But what if the radiation consist of electrons of energy higher than V_1? It does not follow that the number of counts will be undiminished by the field. It will be shown that even if the radiation has energy several times V_1, there will still be an appreciable diminution of the counting rate when the field is applied.

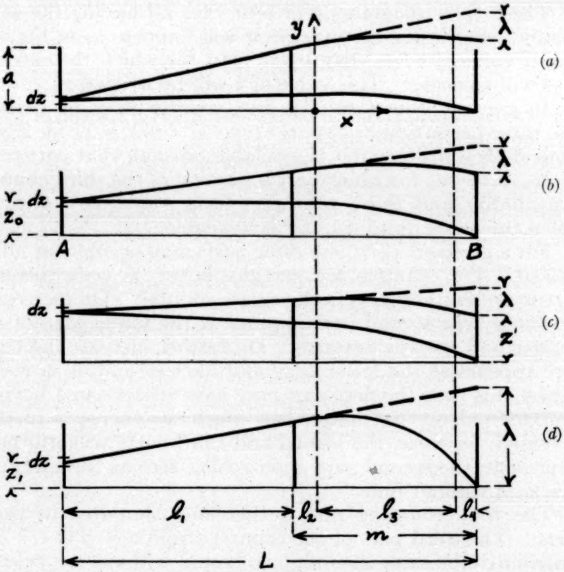
METHOD OF SOLUTION.

The following method enables one to compute the fractional diminution of counting rate, assuming a homogeneous isotropic distribution of cosmic radiation consisting of electrons of either sign and of any energy. The extension to non-homogeneous radiation is then simply a matter of integration.

Considering Fig. 4 ($a - d$), let z and z' represent distances measured from the base line AB along the first and third counters. Let a be the width of the counters and s their dimension perpendicular to the plane of the diagram. Without the magnetic field any element sdz of the first counter may take part in a triple coincidence with any part of the third counter. Thus without the field the contribution of dz to the counting rate is $dn_0 = j(as^2/L^2)dz$ and the total counting rate $N_0 = j(a^2s^2/L^2)$, where j is the number of particles per unit solid angle per square centimeter per second. This assumes that the solid angle subtended by sdz on any point on the third counter is the same for all points.

When the field is applied the contribution of any particular dz may or may not be affected. One must determine whether or not, for any particular dz the available area of the third counter is less than or equal to its actual area. To do this one examines the spread between two extreme rays: one, that ray through dz, through the second counter and through the bottom edge of the third counter; the other, that ray through *dz* and through the upper edge of the second counter. The calculation which follows is then based on the proposition:

FIG. 4.



If the distance between the two extreme rays is equal to or greater than the width of the counter the number of counts is unchanged by the field, and if this distance is less than the width of the counter the number of counts is proportionately diminished. The proof of this rather obvious statement rests on the approximation that the "effective" solid angle subtended by *sdz* on any point on the third counter is the same for all points. This holds with good accuracy for the experiments to be discussed in which the dimensions of the counters are small compared to the distances between them.

Fig. 4(*a*) shows a ray spread greater than the third counter. In Fig. 4*b* the ordinate of dz is increased until the spread equals the counter width. This ordinate will be designated by z_0. Further increase of the ordinate of dz, as in Fig. 4*c*, results in a spread less than the counter width.

These three diagrams represent rays all having the same energy. For lower energy rays it will happen, as in Fig. 4*d*, that a value of z less than a will exist for which the extreme rays will coincide. This value of z will be written z_1.

In general, therefore, the first counter may be divided into three parts: first, that part from $z = a$ to $z = z_1$, for which none of the third counter is available; second, that part from $z = z_1$ to $z = z_0$, for which only a fraction of the third counter is available; and third, that part from $z = z_0$ to $z = 0$ for which the entire third counter is available.

For a given energy these three parts may or may not all be present. For example, for energies below V_1 only the first part is present and covers the entire counter. On increasing the energy the second part appears at the lower edge of the counter and spreads upwards. On further increase the third part appears at the lower edge and likewise moves upwards but by this time the first part may have disappeared beyond the upper edge. No matter how much the energy is further increased, however, the second and third parts will still both be present, the second part approaching zero as the energy is increased without limit.

The total counting rate is therefore computed in three parts. The third part of the counter (from $z = 0$ to $z = z_0$) contributes the same amount as it would without the field.

$$n_3 = j\frac{as^2}{L^2}z_0.$$

The second part (from $z = z_0$ to $z_0 = z_1$) contributes a different amount for each value of z and hence requires an integration. For each value of z there corresponds a value z' on the third counter and an effective area on this counter equal to sz'.
Hence,

$$dn_2 = j\frac{s^2z'}{L^2}dz$$

and

$$n_2 = j\frac{s^2}{L^2}\int_{z_0}^{z_1} z'dz.$$

The first part contributes nothing so that the total counting rate is the sum of the contributions of the second and third parts, or

$$n = \frac{js^2}{L^2}\left[az_0 + \int_{z_0}^{z_1} z'dz\right]. \tag{1}$$

The values z_0 and z_1 represent distances on the first counter, and are computed for the rays shown in diagrams 4*b* and 4*d* respectively. If the values so computed are either less than 0 or greater than a (i.e., if they do not fall on the counter) the value of the nearest counter edge will be taken. When z_1 comes out greater than a one sets it equal to a; when z_0 comes out less than zero one sets it equal to zero.

The problem now lacks only expressions for z_0, z_1, and z' for completion. These values are represented in Figs. 4 *b*, *d*, and *c*), and are either the initial or final ordinates of rays which have the other ordinate specified and which, further, must pass through the top of the middle counter.

Application of the field changes the final ordinate of the ray by an amount which we shall call λ. One can easily verify from Fig. 4*b*, that

$$z_0 = a - \frac{l_1\lambda}{m} \tag{2}$$

and from Fig. 4*d*, that

$$z_1 = \frac{L}{m}a - \frac{l_1}{m}\lambda. \tag{3}$$

The function z' which is the final ordinate of any ray passing through the top of the middle counter is represented by the equation

$$z' = \frac{L}{l_1}a - \lambda - \frac{mz}{l_1}, \tag{4}$$

which, on substituting in (1), gives for the counting rate in the presence of the magnetic field

$$n = \frac{js^2}{L^2}\left\{az_0 + \left(\frac{La}{l_1} - \lambda\right)(z_1 - z_0) - \frac{m}{2l_1}(z_1^2 - z_0^2)\right\}$$

Where z_0 and z_1 are given by equations (2) and (3) subject to the above developed rules, namely, that, when z_1 is greater than a, one sets it equal to a, and that when z_0 is less than zero one puts it equal to zero.

Or since the counting rate without the field is given by $n_0 = ja^2s^2/L^2$, we may write for the fraction permitted by the field

$$p = \frac{n}{n_0} = \frac{z_0}{a} - \frac{1}{a^2}\left(\frac{La}{l_1} - \lambda\right)(z_1 - z_0) - \frac{m}{2l_1a^2}(z_1{}^2 - z_0{}^2). \tag{5}$$

Turning now to the evaluation of λ, or the linear deflection, let us represent the initial ordinate and slope as the ray enters the region of field by y_0 and θ_0 respectively. Without the field the final ordinate will then be

$$z' = y_0 + \theta_0(l_3 + l_4). \tag{6}$$

In the presence of the field both the ordinate and slope at the point where the ray leaves the field region will have been changed. The general relation,

$$z' = y(l_3) + l_4 \frac{dy}{dx}\bigg| l_3,$$

may be written

$$z' = y_0 + \theta_0(l_3 + l_4) + \int_0^{l_3}\int_0^{x} \frac{d^2y}{d\xi^2} d\xi dx + l_4 \int_0^{l_3} \frac{d^2y}{dx^2} dx. \tag{7}$$

Substracting (6) from (7) then gives us for the change in the final ordinate

$$\lambda = \int_0^{l_3}\int_0^{x} \frac{d^2y}{d\xi^2} d\xi dx + l_4 \int_0^{l_3} \frac{d^2y}{dx^2} dx. \tag{8}$$

The two experiments under consideration now require different procedures. In Curtiss' arrangement the energy of an electron is constant along its path, which will consequently be an arc of a circle, but with Mott-Smith the electron continually loses energy as it traverses the iron and hence will follow a spiral path. Proceeding to the simpler case we have, neglecting rest-mass and assuming large radius of curvature,

$$\frac{d^2y}{dx^2} = \frac{1}{\rho} = \frac{HC}{V},$$

whence

$$\lambda_C = \frac{HC}{V}[l_3^2/2 + l_3 l_4], \tag{9}$$

where H is the magnetic force in gauss, c, the velocity of light and V is the potential difference in electromagnetic units corresponding to the energy of the electron.

In the case where energy loss occurs we are fortunate in being concerned with an energy range in which the loss is relatively independent of energy. Anderson[5] has observed with a cloud chamber that the loss per centimeter of lead is about 3.6×10^7 volts. In our calculation of λ for the Mott-Smith experiment, we shall take the value 3×10^7, represent it by v, and assume it to be the same for all energies with which we are concerned. We then start with the equation

$$\frac{d^2y}{dx^2} = \frac{HC}{V - vx}, \tag{10}$$

which leads, when included in (8), to the expression

$$\lambda_M = HC\left\{\frac{1}{v^2}\left[vl_3 + (v - vl_3)\log\left(1 - \frac{v}{V}l_3\right)\right] - \frac{l_4}{v}\log\left(1 - \frac{v}{V}l_3\right)\right\}. \tag{11}$$

In this manner we have computed values of p for both experiments and have plotted them against the common logarithm of energy in volts.* In Fig. 5 are shown curves representing the magnetic cut off characteristics of the two experiments. The line V_{OC} gives the minimum energy capable of affecting Curtiss' counters, and V_{OM} the minimum energy which would record on Mott-Smith's apparatus. Curtiss' counters had 1 mm. steel walls, and therefore a ray would have to penetrate 7 mm. of steel. Using the value of energy loss 3.0×10^7 volts per centimeter in iron we see that an electron would require about 2×10^7 volts energy in order to cause coincident discharges. In Mott-Smith's case, however, an electron would require 4.5×10^8 volts energy to penetrate the iron core. Remembering now that V_0 represents the lowest energy able to record on the apparatus with the field off, and V_1 that with the field on, we make the following tabulation:

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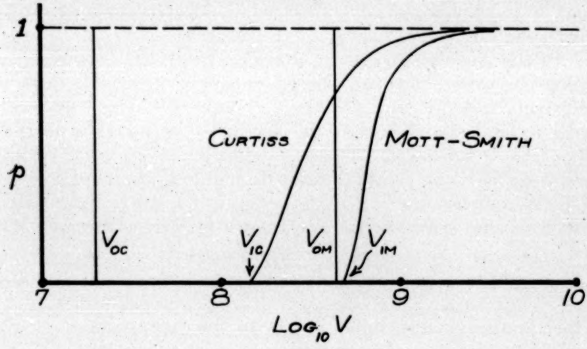
[5] Anderson, *Phys. Rev.*, **43**, 381, 1933.

* The fact that Curtiss actually used four counters affects the calculation in no way whatsoever. The second counter from the top may be treated as not present. Curtiss used four counters instead of three merely to reduce the number of accidental coincidences.

FIG. 5.



	V_0	V_1
Curtiss	2×10^7	1.5×10^8
Mott-Smith	4.5×10^8	4.9×10^8

And since the magnitude of the observed effect depends on the difference between V_1 and V_0 it becomes evident that Mott-Smith's effect should be considerably smaller than Curtiss'.

The actual radiation is, of course, not homogeneous. Suppose, however, that it consists entirely of electrons of either sign distributed as regards energy according to a definite though unknown function $f(V)dV$, which represents the probability that a ray which records on the counters without the field has an energy value between V and $V + dV$. The integral of this function from V_0 to infinity is of course unity. With the field on, however, the probability that a ray, which lies in dV, will be recorded, is $pfdV$, where p may lie between zero and 1. Application of the field will then eliminate a fraction F of the total number of rays equal to

$$\int_{V_0}^{\infty} (1 - p) f dV.$$

Since p is also a function of the field strength, a sufficient number of determinations of F with different fields would enable one to determine the distribution function f. This would involve solving an integral equation and while an analytical method for doing so exists it is probable that some graphical, or trial and error, method could be devised which would consume less time. Since, however, the present data are so meagre, this paper will not go further into this cumbersome matter.

INTERPRETATION OF CURTISS' EXPERIMENT.

Curtiss obtained a value of F equal to 0.30. He interpreted this as showing that 30 per cent. of the ionizing rays were probably electrons of energy less than 10^9 electron-volts. The remainder could be either higher energy electrons or non-deviable ionizing agents such as neutrons. The p-curve as calculated here from the data given in his paper indicates that since the cut-off is complete only for energies under 1.5×10^8 volts and is only 4.3 per cent at 10^9 volts, the number of electrons under 10^9 must be somewhat greater than 30 per cent of the total. In fact, lacking any other knowledge regarding the energy distribution, one could explain Curtiss' results by assuming that the entire cosmic ray spectrum consists of a single line at 4×10^8 volts. If another value of F were available, taken with a different field strength and hence a different p-curve, two lines could be found which would explain the results. By taking enough such readings one could theoretically obtain a distribution curve made up of as many points as one pleased. The practical difficulty lies in getting high enough values of field strength to define the high energy portion of the curve. We know, of course, that the energy spectrum does not consist of a single line and hence our interpretation is confined to certain limiting statements such as the following. If the radiation consist entirely of electrons of either sign, the number between 2×10^7 volts and 1.5×10^8 volts is less than 30 per cent. of the total above

2×10^7 volts; the number between 2×10^7 and 10^9 volts is greater than 30 per cent. of the total.

COMPARISON OF EXPERIMENTS OF CURTISS AND OF MOTT-SMITH.

As is shown in Fig. 5, Mott-Smith's apparatus eliminated a greater proportion of high energy rays than did Curtiss'. The fact that his observed fraction (F) eliminated was only about 0.06 (only slightly greater than his probable error) while Curtiss' effect was 0.30, has excited speculation as to whether the magnetic induction B is really the appropriate vector from which to compute the deflection. To reconcile the results, Curtiss himself suggested [4] that the iron in Mott-Smith's experiment absorbed or scattered all or nearly all of the rays of sufficiently low energy for his magnetic field to deflect. During the preparation of this paper the same suggestion was made by E. L. Hill.[6]

Other types of explanation have been put forward on the grounds of scattering of rays and production of secondaries within the iron core. It is suggested that deviations produced by atomic fields may so broaden the beam as to mask the magnetic deflection. This scattering effect is of course present both with the field and without, so that the effect of magnetic deflection should be present in the comparative results. Mott-Smith showed that the presence of the iron produced no drastic broadening. He measured the counting rate with his lower counter shifted to various positions away from the central one and found that, within his limits of accuracy, the presence of the iron did not change the distribution. We expect therefore that the cut-off curve derived here for the Mott-Smith experiment is not seriously affected by simple scattering.

T. H. Johnson [7] has suggested that Mott-Smith's negative result may be accounted for by production of secondaries within the iron. One imagines a high energy, relatively nondeviable, and relatively nonionizing primary ray, accompanied in its path by one or more ionizing secondaries such as 10^8 volt electrons. This ray group traverses the first two counters and discharges them by the action of the highly ionizing secondaries. In passing through the iron, however, the original secondaries are absorbed and the discharge of the third counter is produced by other secondaries generated by the primary shortly before it leaves the iron. Therefore, although the third counter is activated by a deviable ray, this ray has only passed a short distance through the deviating field. Thus, with this view the responsibility for failure to observe the expected deflection no longer lies with the magnitude of the magnetic vector. This process is, of course, beyond the realm of the present calculations. The present work, however, does support the view that Mott-Smith's lack of definite effect can be accounted for simply by absorption of the rays by the iron. The fact that Mott-Smith's minimum detectable energy V_0 was very close to his cut-off energy V_1 while a wide separation existed between the two values in Curtiss' experiment would lead one to predict that the former's effect would be very much smaller than the latter's. Mott-Smith did, in fact, observe the absorption in his iron to be 25 per cent. of the total radiation. Thus, were his p-curve coincident with Curtiss', his effect would be 5 per cent., provided that the same distribution function $f(V)$ existed in both cases. The fact that he cut off somewhat higher energies than did Curtiss would mean that he should have obtained an effect somewhat greater than 5 per cent. He actually did have an effect of about 6 per cent. which, since it is slightly greater than his standard deviation, has a good chance of being real. Therefore, when one considers the uncertainties arising from (*a*) possibility of different distribution functions in the two cases, and (*b*) statistical fluctuations in counting rates, it becomes evident that no real discrepancy exists as far as one can tell.

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[6] Hill, *Rev. Sci. Instr.*, **4**, 570, 1933.

[7] Johnson, *Phys. Rev.*, **40**, 468L, 1932.

With the hope of providing more conclusive evidence on this point, Dr. Swann and the writer have under way another deflection experiment in iron, in which the thickness of the iron traversed by the rays will be the same as Mott-Smith's but in which the energy below which all electrons are eliminated will be greater than Mott-Smith's.

The writer wishes to thank Dr. Swann for discussions of the foregoing problem and for verifying, independently, the expression for p derived above.

Off-flavor in Ice Cream.—A stale, tallowy, metallic, decidedly objectionable taste may develop in ice cream flavored with certain fruits, such as strawberries and pineapple. C. D. DAHLE and E. C. FOLKERS (*Jour. Dairy Science*, 1933, XVI, 529–547) have made an elaborate study of the factors which contribute to the development of this off-flavor. It is due to the presence of copper and of the acid of the fruit. The copper is a contamination in the dried or condensed (concentrated) milk used in the mix, and is derived from the copper vacuum pan used in the evaporation of the water from fresh milk. When 1.3 part of copper per million is present in the ice cream, off-flavor develops. The type of strawberries (fresh, cold pack, canned) and the quality of the milk product used in the ice cream have little or no influence on the appearance of off-flavor. Heating the berries and the mix at a temperature of 180° F. for 1 hour does not insure absence of off-flavor. The appearance of off-flavor is delayed by neutralization of the berries to a hydrogen ion concentration of pH 7.0; however, this procedure injures the natural flavor of strawberries.

J. S. H.

SIMPLE ULTRA SHORT WAVE WAVEMETERS.

BY

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SUMMARY.

A description is given of some simple absorption type wavemeters which have been constructed for wave-lengths down to 45 centimeters.

It has been the universal practice in measuring wave-lengths of the order of one or two meters and less, to make use of Lecher wire systems as wavemeters. Standing waves are produced on two long parallel wires loosely coupled to the oscillator whose wave-length is to be determined. Potential or current nodal points on the standing waves are indicated by means of a thermogalvanometer or neon tube bridging the wires and sliding along them. The wave-length is found by actually measuring the interval between successive nodal points, this distance being equal to one-half the wave-length. If several standing waves are produced, the average will give the wave-length to a reasonably high degree of accuracy. If sufficient care is taken the result may be relied upon to within one-quarter of one per cent.

The Lecher wires wavemeter is very satisfactory for making precision measurements of specific wave-lengths. It is often desirable, however, to make a number of wave-length measurements quickly where accuracy is of secondary importance, the prime requisites being convenience and rapidity of measurement. For such an application the ordinary absorption type of wavemeter, consisting of an inductance and variable condenser, would be very convenient.

Several wavemeters of this type were constructed by the author for use in connection with some investigations on ultra short wave oscillators.[1] These are shown in the illustration, and their calibration curves given in Plates I and II. Calibration was done by means of Lecher wires. Resonance was indicated by a deflection on the plate current meter when either Lecher wires or wavemeter was coupled sufficiently closely to the oscillator and tuned to the wave-length of the oscillations.

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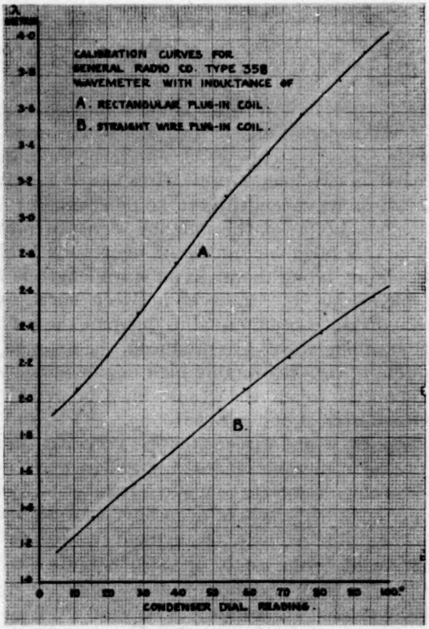
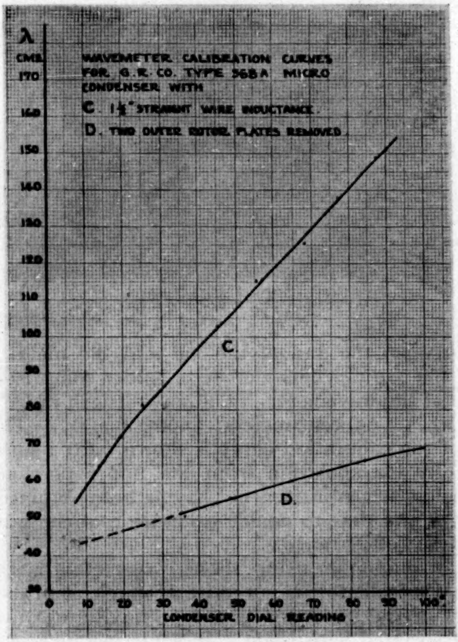
[1] "A Particular Case of High Frequency Electron Oscillations," by W. H. Moore. *Can. Jour. of Research*, May, 1931.

Plate I.



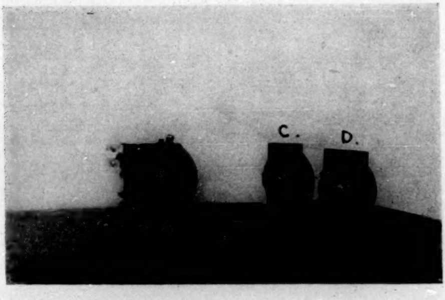
The single turn coil in the center of the photograph is the regular 4 to 6 meter inductance used in conjunction with the condenser shown at the left to form a commercial type of ultra short wave wavemeter. Two other inductances, *A* and *B* in the photograph, were constructed to be used with this same condenser. The range covered by the wavemeter with the rectangular coil *A* is from 2 to 4 meters, and with the straight wire coil *B* is from 1.2 to 2.6 meters, or 200 to 400 and 120 to 260 centimeters, respectively.

PLATE II.



Wavemeter *C* consists of a miniature variable condenser of 15 micromicrofarads maximum capacity, in parallel with an inductance composed of a straight piece of wire 1½ inches long connected directly between rotor and stator, as shown in the photograph. The wave-length range covered is from 60 to 150 centimeters.

The lowest range wavemeter constructed is that shown as "*D*." It consists of a small five plate variable condenser of the same type as used in wavemeter "*C*," but having two of the three rotor plates removed. The soldering lug on the stator is turned towards the rotor shaft and a globule of solder placed between the end of the lug and the metal bushing carrying the rotor. This globule of solder comprises the inductance of the wavemeter. The wave-length range covered is from 45 to 65 centimeters, approximately. The lower portion of the calibration curve is shown dotted since it was obtained by extrapolation from the upper portion, wavelengths below 50 centimeters not having been obtained experimentally at the time to enable calibration of the wavemeter over this part of its range.



Wavemeters for λ's of $\frac{1}{2}$ to 6 meters.

The technique in using these wavemeters with Barkhausen-Kurz oscillators is not quite so simple as in the case of oscillators of the usual reaction type having definite tuned circuits associated with them. In some instances a marked deflection of the plate milliammeter can be obtained with the wavemeter six inches distant from the oscillator valve, even when there is no tuned Lecher wire circuit connected to the valve. More often it is necessary to hold the wavemeter against the glass envelope of the valve producing the Barkhausen-Kurz oscillations. The wavemeter is then turned in all directions until a position is found in which a deflection of the plate milliammeter can be produced when the wavemeter is tuned to resonance. Any deflection of the grid milliammeter occurring when the wavemeter is tuned to resonance, is too slight to be observed, and hence cannot be utilized as an indication of resonance.

This series of wavemeters is of particular interest inasmuch as it permits a positive check to be maintained at all times on the wave-lengths produced. The fundamental wave-length of oscillation of any particular circuit can always be ascertained definitely, with no possibility of mistaking a harmonic for the fundamental. By making use of a series of wavemeters covering from the shortest waves produced up to four or five meters, it is possible to determine very rapidly whether a 75 centimeter wave, for example, whose presence is indicated, is a harmonic of a higher wave-length fundamental, or is itself the fundamental. The accuracy of these wavemeters is no greater than that of the Lecher wire measurements from which they are calibrated, but their usefulness lies in the fact that they indicate but one wave-length at a time, will seldom indicate a harmonic at all unless its intensity be very great, and in any case can immediately be tuned to double or three times the indicated wave-length to determine whether a higher wave is present or not.

By the exercise of a little mechanical ingenuity wavemeters of this type for even shorter wave-lengths can be constructed.

Retention of Ingested Aluminum.—In the *Journal of the American Medical Association* has appeared an account of the investigations by Schwartze, Cox, Unganst, Murphy and Wigman on the extent of the retention of ingested aluminum by guinea-pigs. It was concluded that: (1) the aluminum content of fresh tissues of guinea-pigs receiving no added aluminum is about 0–4 part per million or less; (2) feeding of large amounts of soluble aluminum salts produces a barely detectable deposition of aluminum in the soft tissues (less than 0.5 part per million) and somewhat larger amounts (from 0.5 to 1 part per million) in carcasses; (3) no systematic pharmacologic effects can be ascribed directly to absorbed aluminum nor does aluminum appear to be cumulative in the tissues; and (4) no harmful effects can be expected from soluble aluminum occurring naturally in foods or introduced by utensils into a diet of normal phosphorus content.

C.

SOME TRANSMISSION LINE TRANSIENTS. GRAPHICAL EVALUATION BY FOURIER'S SERIES.

BY

J. A. STRELZOFF, M.E.E.*

Synopsis

By neglecting a relatively small term and thus making a slight simplification in the Heaviside's Operational Equations of line transients, the latter are shown to be reduced to forms involving Fourier's Series. A synthetic analysis of these series together with the wave shape of the series for some particular points, as well as the symmetry conditions involved, makes it possible to draw the general wave shape corresponding to the given series, thus substituting a simple graphical method in place of the usual laborious calculations for the evaluation of line transients.

The following cases are treated:

(*a*) Short-circuited line: (1) current and (2) voltage.
(*b*) Open line: (1) current and (2) voltage.
(*c*) Two lines fed from the same source, one line being grounded and the other open.

INTRODUCTION.

The purpose of this paper is to show how, by neglecting a relatively small term and thus introducing an approximation valid for power transmission lines, the Heaviside operational equations of transients are reduced to a form with identifiable Fourier Series. These series happen to represent outlines consisting of broken straight lines, and it then becomes a simple matter to draw the transient disturbance at any point on the line as a function of time, thus substituting a simple graphical method in place of the usual laborious analytical task.[1] As an application of the method here described, waves obtained for different instants may be cut out of cardboard and placed together to form a three-dimensional model illustrating the whole transient disturbance as a function of both time and space (Figs. 6 and 7).

The operational equations for the following simple cases will be discussed here:

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[1] See Bush, "Operational Circuit Analysis," Ch. 12.

(*a*) Transmission line short-circuited at the receiver end.

(*b*) Transmission line open at the receiver end.

(*c*) Two transmission lines fed from the same source; one line short-circuited and the other open.

In all cases a disturbance is assumed to be caused by a resistanceless d.c. source suddenly applied at the instant $t = 0$.

With a quantitative knowledge of the phenomena involved in the foregoing cases, one can estimate the limits of transient current and voltage under other given conditions. For example, with a large inductance connected across the line, when a traveling wave reaches it, the first voltage rise is the same as if the line were open. Then the energy of the wave gradually passes through the inductance, and, if the wave is sufficiently long, the final conditions are practically those of a short-circuited line.

1. OPERATIONAL EQUATIONS.

The operational equations for the current i and the voltage e, as functions of time and space, are as follows:[2]

(*a*) Short circuited line.
$$i = (n \cosh nx/Z \sinh nl)E1$$
$$e = (\sinh nx/\sinh nl)E1.$$

(*b*) Open line.
$$i = (Y \sinh n(l - x)/n \cosh nl)E1$$
$$e = (\cosh n(l - x)/\cosh nl)E1.$$

Applying, in a known manner, Heaviside's Expansion Theorem to the foregoing equations, for a line with no leakage, that is $G = 0$, we obtain

(*a*) Short-circuited line.

$$i = I_s(1 - e^{-2at}) + (Ee^{-at}/Ll) \sum_1^\infty (2 \cos mx/B_1 \cos s\pi) \sin B_1 t \qquad (1)$$

$$e = E\left(x/l + e^{-at} \sum_1^\infty \frac{2(-1)^s \sin (s\pi x/l)}{\pi s} \times ((a/B_1) \sin B_1 t + \cos B_1 t)\right). \qquad (2)$$

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[2] See notation at the end of the paper. For a derivation and analytical solution of these equations see, for example, Berg, Heaviside's "Operational Calculus," Ch. 15.

(*b*) Open line.

$$i = (2E/Ll)e^{-at} \sum_{1}^{\infty} (\sin (k\pi x/2l)/\sin (k\pi/2)) \sin B_2 t \qquad (3)$$

$$e = E(1 - e^{-at} \sum_{1}^{\infty} ((4 \cos (k\pi x/2l)/k\pi \sin (k\pi/2)) \times ((a/B_2) \sin B_2 t + \cos B_2 t)). \qquad (4)$$

Each equation contains an infinite series so that they do not directly reveal the form of the waves. They all contain either sine or cosine terms of $B_1 t$ or $B_2 t$, and thus may be said to represent the summation of an infinite number of sine waves. The resultant wave may or may not be a periodic function of t or of x, because B_1 and B_2 are involved functions of variable integers s and k, given by

$$B_1 = ((s^2\pi^2/LCl^2) - (R^2/4L^2))^{\frac{1}{2}} \qquad (5)$$

$$B_2 = ((k^2\pi^2/4LCl^2) - (R^2/4L^2))^{\frac{1}{2}}. \qquad (6)$$

Heretofore the only way to evaluate the right-hand sides of equations (1), (2), (3) and (4) has been to compute the series term by term, for successive values of s or k until the terms become small enough to be neglected. This is an exceedingly laborious task even for a single point on the line, since the series are very slowly convergent.[3] Thus an exact numerical solution for e and i is extremely difficult to obtain.

The simplification described in this paper is to neglect the second term, $R^2/4L^2$, in the expressions for B_1 and B_2, which term is very small in comparison with the first term, even for $s = 1$ or $k = 1$. Eqs. (5) and (6) are then simplified to

$$B_1' = (s\pi)/(l(LC)^{\frac{1}{2}}) = sb \qquad (7)$$

$$B_2' = (k\pi)/(2l(LC)^{\frac{1}{2}}) = (kb)/2. \qquad (8)$$

This approximation is permissible for power lines and the equations (1), (2), (3) and (4) are thereby converted into Fourier Series. Such an approximation still leads to a result of very high degree of accuracy, higher than that one obtained by usual computations accurate to a limited number of significant places.[4] Eqs. (1) to (4) become

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[3] See, for example, Bush, "Operational Circuit Analysis," Ch. 12.

[4] See Bibliography 3, H. C. Knutson's thesis, page 21.

(*a*) Short-circuited line.

$$i = I_s(1 - e^{-2at}) + EFe^{-at} \sum_1^\infty (2(-1)^s/s\pi) \cos (s\pi x/l) \sin (sbt) \quad (9)$$

$$e = E(x/l + e^{-at} \sum_1^\infty (2(-1)^s/s\pi) \sin (s\pi x/l) \cos (sbt) + RLFe^{-at} \sum_1^\infty ((-1)^s/(s\pi)^2) \sin (s\pi x/l) \cos (sbt). \quad (10)$$

(*b*) Open circuit line.

$$i = -EFe^{-at} \sum_1^\infty (4(-1)^{(k+1)/2}/k\pi) \sin (k\pi x/2l) \sin (kbt/2) \quad (11)$$

$$e = E(1 + e^{-at} \sum_1^\infty 4(-1)^{(k+1)/2}/k\pi) \sin (kx\pi/2) \cos (kbt/2) + RLFe^{-at} \sum_1^\infty (-1)^{(k+1)/2}/(k\pi)^2 \sin (k\pi x/2) \sin (kbt/2). \quad (12)$$

The eqs. (9) to (12) may be represented as a combination of appropriate simpler component curves, viz., exponential and zigzag straight lines. The next step is to identify the resulting wave shapes represented by the foregoing component Fourier Series.

2. SYNTHESIS BY FOURIER SERIES.[5]

The following is the well known general expression of a Fourier Series of a function of *bt*:

$$f(bt) = 0.5\, A_0 + \sum_1^\infty A_s \cos (sbt) + \sum_1^\infty B_s \sin (sbt), \quad (13)$$

where the coefficients *A* and *B* are determined by the familiar equations,

$$A_s = 1/\pi \int_0^{2\pi} f(bt) \cos (sbt) d(bt) \quad (14)$$

$$B_s = 1/\pi \int_0^{2\pi} f(bt) \sin (sbt) d(bt). \quad (15)$$

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[5] See for example Dr. Malti's "Electric Circuit Analysis," Ch. XIII, for a discussion of Fourier's Series and the effect of various symmetries in the wave shape on the form of the series, and the evaluation of the coefficients.

Each Fourier Series component contained in eqs. (9) to (12) may be represented as follows:

$$y = \sum_1^\infty \sin x \sin (bt), \tag{16}$$

thus containing elements depending on x and those depending on t. In what follows the variable x will be held constant, the wave shape so obtained being a function of t. Wave shapes could also be obtained as functions of x, for desired constant values of t, but the procedure is somewhat more involved, as may be readily seen by inspection of eqs. (9) to (12).

We shall now show in detail how to identify the series expressions in eqs. (9) to (12) with certain simple curves.

(a) Short-circuted Line.

(1) *Current.* Eq. (9) contains the following Fourier's Series:

$$y = \sum_1^\infty ((2(-1)^s)/(s\pi)) \cos (s\pi u_1) \sin (sbt). \tag{17}$$

This series is of the type,

$$f(bt) = \sum_1^\infty B_s \sin (sbt), \tag{18}$$

where the coefficients B_s are defined by equation (16). This series possesses a symmetry of the type,

$$f(bt) \equiv -f(-bt). \tag{19}$$

Note the following three particular values of the right-hand side of eq. (17):

When $u_1 = 1$,

$$y = (-2/\pi)(\sin bt - 1/2 \sin (2bt) + 1/3 \sin (3bt) \ldots \text{etc.}).$$

This corresponding curve is shown in Fig. 1.[6]

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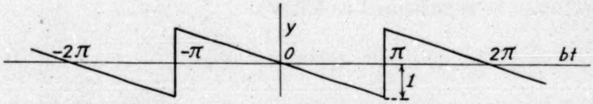
[6] For numerous curves defined by Fourier's Series see Berg's "Operational Calculus," pp. 169–172.

FIG. 1.



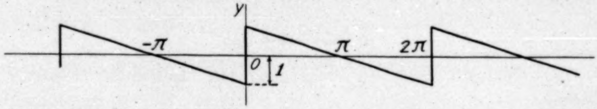
Short-circuited line. Transient current. Wave shape of the series eq. 17 at the short-circuited end.

When $u_1 = 0$

$$y = (2/\pi)(\sin(bt) + (1/2)\sin(2bt) + (1/3)\sin(3bt)\ \dots\ \text{etc.}). \qquad (20)$$

This curve is shown in Fig. 2.

FIG. 2.



Short-circuited line. Transient current. Wave shape of the series eq. 17 at the source end.

When $u_1 = 0.5$

$$y = -(1/\pi)(\sin(2bt) - (1/2)\sin(4bt) + (1/3)\sin(6bt)\ \dots\ \text{etc.}). \qquad (21)$$

This series defines the same wave shape as in Fig. 1, only with double the frequency and half the amplitude.

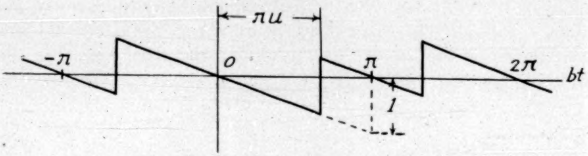
On the basis of the wave shapes at the above three points we now *assume* the wave shape shown in Fig. 3 to obtain at any point on the line. This guess is much simplified by the conditions of symmetry in eq. (17) which make it necessary to preserve the general sawtooth shape of the curve, with vertical discontinuities.

To prove that the assumed wave form in Fig. 3 satisfies eq. (17), we evaluate the coefficient B_s defined by eq. (15), taking $f(bt)$ as indicated in the legend to Fig. 3.

$$B_s = \frac{2}{\pi}\left(\int_0^{\pi u} -(bt/\pi)\sin bt\, d(bt) + \int_0^{\pi}((\pi - bt)/\pi)\sin bt\, d(bt)\right) = (2/s\pi)\cos(s\pi u). \qquad (22)$$

Substituting this value in eq. (18), we obtain eq. (17), which proves the correctness of the assumption of Fig. 3.

FIG. 3.



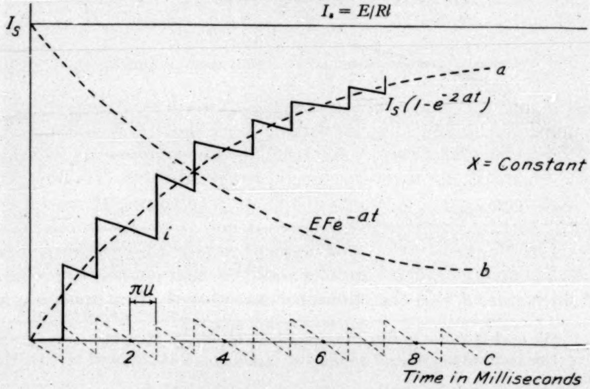
$$y = bt/\pi \qquad \text{for} \qquad 0 < bt < \pi u$$
$$y = (\pi - bt)/\pi \qquad \text{for} \qquad \pi u < bt < \pi$$
$$f(bt) \equiv -f(-bt).$$

Short-circuited line. Transient current. General wave shape of the series of eq. 17.

We now have all the elements necessary for drawing a complete curve of "current vs. time." It will be seen from eq. (9) that this curve may be combined out of the following three component curves (see Fig. 4):

(a) $I_s(1 - e^{-2at})$
(b) EFe^{-at}
(c) $\sum_1^\infty (2\,(-1)^s/s\pi) \cos (s\pi u) \sin bt.$

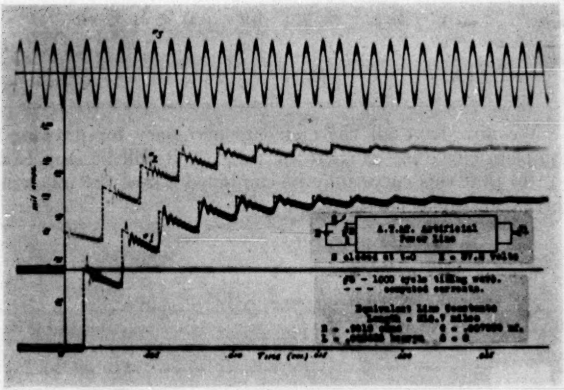
FIG. 4.



Short-circuit current at a point 0.7 from the source.

The first two components are the same for any point on the line, being functions of time only, the third component is represented by the general curve in Fig. 3 and must be drawn for a particular value of u. Multiplying the ordinates of the curve (c) by the corresponding ordinates of the curve (b) and adding the ordinates of the curve (a) the final curve is obtained. Having drawn such resultant curves for several points on the line, they may be combined into a three-dimensional model (Fig. 6),[7] using x as the third dimension.

FIG. 5.



Oscillogram of currents at the two ends of a short-circuited artificial line.

Experimental Check. An oscillogram of currents at the two ends of a short-circuited artificial line (taken at Lehigh University) is shown in Fig. 5.[8] In taking this oscillogram the line was shorted at the far end through an element of an oscillograph; a second element was connected in series with a battery and a contactor at the near end of the line. At an instant $t = 0$ the contactor was closed, thus applying a

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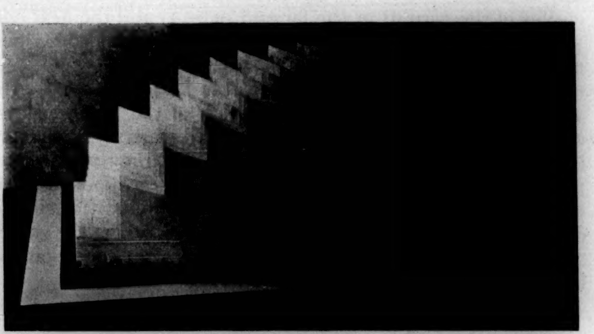
[7] The models shown in Figs. 6, 7 were built by Mr. J. Murphy.

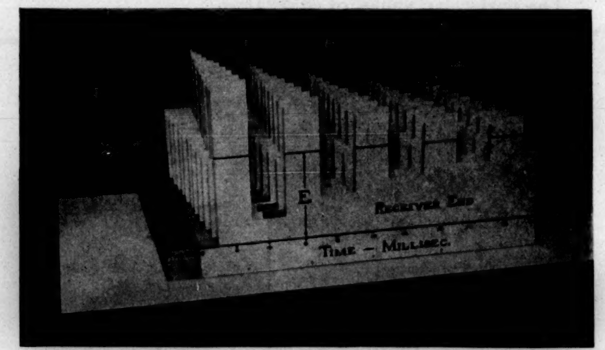
[8] This oscillogram, as well as the one of Fig. 14, was obtained by Mr. H. Knutson.

FIG. 6.



Model showing the short circuit current. Variation with time and distance along the line.
Characteristics of the line:
R = 0.341 ohms per loop mile
L = 0.00213 henries per loop mile
$C = 0.014 \times 10^{-6}$ farads per loop mile
l = 133 miles. E = applied voltage

FIG. 7.



Model showing at the open circuit voltage. Variation with time and distance along the line.
Characteristics of the line:
R = 0.341 ohms per loop mile
L = 0.00213 henries per loop mile
$C = 0.014 \times 10^{-6}$ farads per loop mile
l = 133 miles. E = applied voltage

d.c. voltage to the line. The dotted lines are the theoretical curves of the current at the far end ($u = 1$) and the near end ($u = 0$) obtained for the same line by the method described above.

It will be seen that the theoretical and experimental curves agree quite closely, with the exception of the points of discontinuity, where the experimental curves start to rise slightly before the theoretical curves. This discrepancy may be explained in part by the sluggishness of the moving element of the oscillograph used and in part by a few simplifications introduced into the theoretical deductions and by taking the values of the parameters R, L and C for the transient conditions to be the same as for the steady state.

(2) *Voltage.* Eq. (10) contains two series terms,

$$y = \sum_{1}^{\infty} - (2/s\pi) \sin (s\pi u) \cos (sbt) \tag{23}$$

and

$$y = \sum_{1}^{\infty} - (1/(s\pi)^2) \sin (s\pi u) \sin (sbt). \tag{24}$$

These will be treated separately.

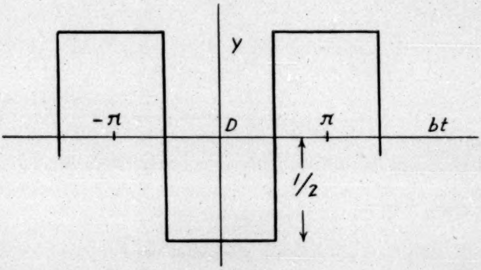
The particular values of eq. (23) are:

When $u = 0$ or 1, $y = 0$; when $u = 0.5$,

$$y = - (2/\pi)(\cos bt - (1/3) \cos 3bt + (1/5) \cos 5bt \ldots \text{etc.}). \tag{25}$$

This curve is shown in Fig. 8.

FIG. 8.



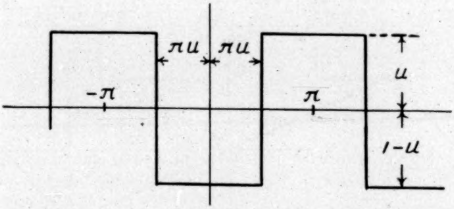
Short-circuited line. Transient voltage. Wave shape of the series eq. 23 at the middle point of the line.

The general wave for any point on the line must then be consistent with these three results. And, further, since the series must contain only cosine terms it must satisfy also the symmetry condition that

$$f(bt) \equiv f(-bt); \qquad (26)$$

it also must have the same area above and below the axis since there is no constant term. The curve satisfying all these conditions is shown in Fig. 9.

FIG. 9.



Short-circuited line. Transient voltage. General wave shape of the series eq. 23.

$$y = -(1-u) \qquad 0 < bt < \pi u$$
$$y = u \qquad \pi u < bt < \pi$$
$$f(bt) \equiv f(-bt).$$

A check similar to the one used in the case of the current wave proves that the assumed curve corresponds to the given series of eq. (23).

The particular values of eq. (24) are:

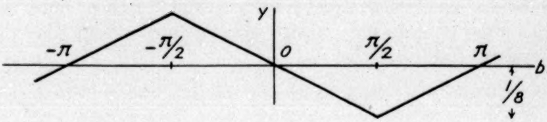
When $u = 0$ or 1, $y = 0$; when $u = 0.5$,

$$y = -(1/\pi^2)(\sin bt - (1/3^2)\sin 3bt + (1/5^2)\sin 5bt \ldots \text{etc.}).$$

This curve is shown in Fig. 10.

The assumed general wave must then satisfy these three

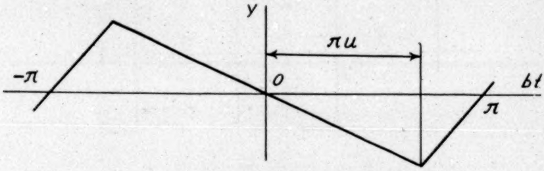
FIG. 10.



Short-circuited line. Transient voltage. Wave shape of the series eq. 24 at the middle point of the line.

particular conditions and also the symmetry condition given by the eq. (19) The wave of Fig. 11 fits these conditions and checks the series of eq. (24).

FIG. 11.



$$y = -\frac{(1-u)bt}{2\pi}\ ; \quad 0 < bt < \pi u$$

$$y = -\frac{u(\pi - bt)}{2\pi}\ ; \quad \pi u < bt < \pi$$

$$f(bt) \equiv -f(-bt).$$

Short-circuited line. Transient voltage. General wave shape of the series eq. 24.

The complete curve in this case is obtained by combining the different component curves as defined by eq. (10), as shown for the case of current in Fig. 4.

(b) Open-circuit Line.

(1) *Current.* Eq. (11) contains the following series:

$$y = \sum_{1}^{\infty} (4/k\pi) \cos (ku\pi/2) \sin (kbt/2). \qquad (27)$$

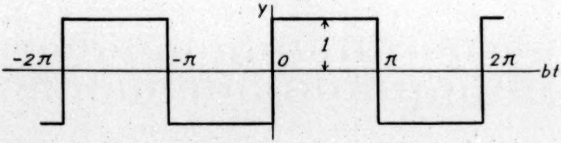
The particular values of eq. (27) are:

When $u = 1$, $y = 0$; when $u = 0$,

$$y = (4/\pi)(\sin(bt/2) + (1/3)\sin(3bt/2) + (1/5)\sin(5bt/2)\ .\ .\ .\ \text{etc.}). \qquad (28)$$

This curve is shown in Fig. 12.

FIG. 12.



Open circuit line. Transient current. Wave shape of the series eq. 27 at the source.

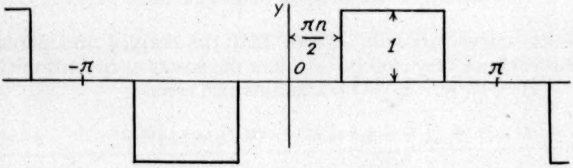
The series of eq. (27) contains only odd sine terms. Hence the wave shape defined by it must possess the following symmetries:

$$f(bt) \equiv -f(-bt) \qquad (29)$$

$$f(bt) \equiv -f(\pi + bt). \qquad (30)$$

The curve shown in Fig. 13 satisfies all these conditions.

FIG. 13.



$$y = 0 \qquad 0 < bt < \frac{\pi u}{2}$$

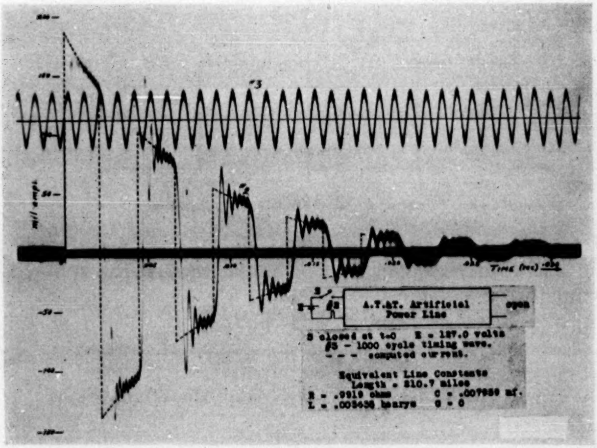
$$y = 1 \qquad \frac{\pi u}{2} < bt < \frac{\pi}{\pi}.$$

Open circuit line. Transient current. General wave shape of the series eq. 27.

The complete curve of "current vs. time" is obtained by combining the component curves of eq. (11) as described before for the case of the shorted line.

Experimental Check. An oscillogram of the current of an open line is shown in Fig. 14. The dotted curve is the theoretical curve. It will be seen that the derived and actual curves check very closely, except at the points of discontinuity.

FIG. 14.



Oscillogram of the transient current at the source of an artificial open line.

(2) *Voltage.* Eq. (12) contains two series:

$$y = \sum_{1}^{\infty} (-4/k\pi) \sin (k\pi u/2) \cos (kbt/2) \tag{31}$$

$$y = \sum_{1}^{\infty} (-4/(k\pi)^2) \sin (k\pi u/2) \sin (kbt/2). \tag{32}$$

The particular values of eq. (31) are:

When $u = 0$, $y = 0$; when $u = 1$,

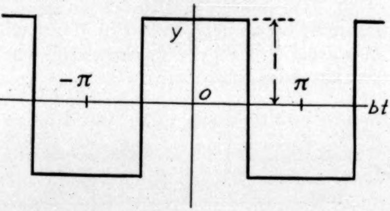
$$y = (-4/k\pi)(\cos (bt/2) - (1/3) \cos (3bt/2) + (1/5) \cos (5bt/2) \ldots \text{etc.}).$$

This curve is shown in Fig. 15.

The series of eq. (31) is of the type:

$$y = \sum_{1}^{\infty} B_k \cos (kbt), \tag{33}$$

FIG. 15.



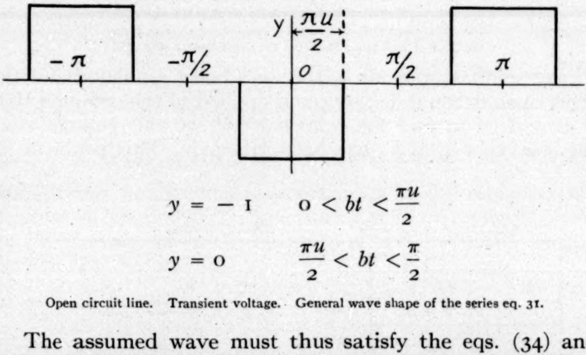
Open circuit line. Transient voltage. Wave shape of the series eq. 31 at the open end.

possessing the following symmetries:

$$f(bt) \equiv + f(-bt) \tag{34}$$

$$f(bt) \equiv - f(\pi - bt). \tag{35}$$

FIG. 16.



$$y = -1 \qquad 0 < bt < \frac{\pi u}{2}$$

$$y = 0 \qquad \frac{\pi u}{2} < bt < \frac{\pi}{2}$$

Open circuit line. Transient voltage. General wave shape of the series eq. 31.

The assumed wave must thus satisfy the eqs. (34) and (35) as well as the particular values of eq. (31) and is shown in Fig. 16. The check as to the correspondence of the assumed wave to the series of eq. (31) may be made as shown before.

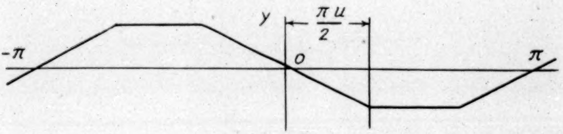
Eq. (32) has the following particular values:

When $u = 0$, $y = 0$; when $u = 1$,

$$y = (-4/\pi^2)(\sin bt - (1/3^2)\sin 3bt + (1/5^2)\sin 5bt \ldots \text{etc.}). \quad (37)$$

The series of eq. (37) is identical to the series of eq. (26) and may be represented by a curve as in Fig. 9 but with an amplitude four times greater. Figure 17 shows the wave shape corresponding to the series of eq. (32).

FIG. 17.



$$y = -\frac{bt}{\pi} \qquad 0 < bt < \frac{\pi u}{2}$$

$$y = -\frac{u}{2} \qquad \frac{\pi u}{2} < bt < \frac{\pi}{2}.$$

Open circuit line. Transient voltage. General wave shape of the series eq. 32.

(c) Case of Two Lines Fed from the Same Source (Fig. 18).

We shall assume one of the lines being grounded and the other open, when a d.c. source is applied to the common bus. It is desired to find the transient current and voltage after the source of E.M.F. has been inserted. This problem is

FIG. 18.

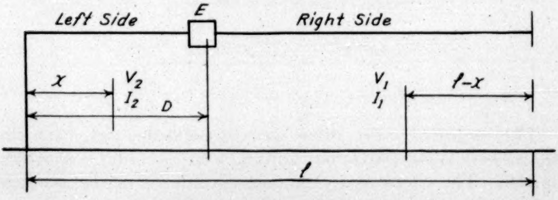


Diagram. Two lines fed from the same source.

considered in Berg's "Heaviside Operational Calculus" on page 103 where the operational equations of voltage are given. The operational equations for current may be obtained by integrating the corresponding expression for voltage. Thus the four operational equations are:

$$V_1 = (\cosh nD/\cosh nl) \cosh n(l - x)E1 \tag{38}$$

$$I_1 = (Y \cosh nD/n \cosh nl) \sinh n(l - x)E1 \tag{39}$$

$$V_2 = -(\sinh n(l - D)/\cosh nl) \sinh nxE1 \tag{40}$$

$$I_2 = -(Y \sinh (nl - D)/\cosh nl)n \cosh nxE1. \tag{41}$$

Applying to the solution of the eqs. (38) to (41) the Heaviside Expansion Theorem and simplifying the resulting expressions, we obtain:

$$\begin{aligned} V_1 = E + E \sum_1^\infty (4\,(-1)^{(k+1)/2} &\cos (k\pi D/2l) \\ &\times \cos (k\pi u/2)(1/k)e^{-at})(a \sin Bt/b) + \cos/bt) \end{aligned} \tag{42}$$

$$\begin{aligned} I_1 = E \sum_1^\infty -2\,(-1)^{(k+1)/2} &\sin (k\pi u/2) \cos (k\pi D/2l) \\ &\times (1/LBl)e^{-at} \sin Bt \end{aligned} \tag{43}$$

$$\begin{aligned} V_2 = E \sum_1^\infty 4\,(-1)^{(k+1)/2} &\sin (k\pi(l - D)/2l) \\ &\times \sin (k\pi(1 - u)/2)(1/k)e^{-at}((a \sin Bt/b) + \cos Bt) \end{aligned} \tag{44}$$

$$\begin{aligned} I_2 = E \sum_1^\infty 2\,(-1)^{(k+1)/2} &\sin (k\pi(l - D)/2l) \\ &\times \cos (k\pi(1 - u)/2)(1/LBl)e^{-at} \sin Bt \end{aligned} \tag{45}$$

Simplifying further the above equations by replacing the product of trigonometric functions by a corresponding sum and neglecting (as in the cases (*a*) and (*b*)) $R^2/4L^2$, the eqs. (42) to (45) become

$$\begin{aligned} V_1 = E + Ee^{-at}((A_2/2) \sum_1^\infty 4\,(-1)^{(k+1)/2}&(1/(\pi k)^2) \\ &\times \cos (k\pi w/2) \sin (kbt/2) \\ + (A_2/2) \sum_1^\infty 4\,(-1)^{(k+1)/2}(1/(\pi k)^2 &\cos (k\pi v/2) \\ &\sin (kbt/2) \end{aligned}$$

$$+ \sum_1^\infty 2\,(-\,1)^{(k+1)/2}(1/\pi k)\cos(k\pi w/2)\cos(kbt/2)$$

$$+ \sum_1^\infty 2\,(-\,1)^{(k+1)/2}(1/\pi k)\cos(k\pi v/2)\cos(kbt/2)). \tag{46}$$

$$V_2 = Ee^{-at}((A_1/2)\sum_1^\infty 4\,(-\,1)^{(k+1)/2}(1/(k\pi)^2$$

$$\times \cos(k\pi\beta/2)\sin(kbt)$$

$$+ (A_1/2)\sum_1^\infty -\,4\,(-\,1)^{(k+1)/2}(1/(k\pi)^2$$

$$\times \cos(k\pi\alpha/2)\sin(kbt)$$

$$+ \sum_1^\infty 2\,(-1)^{(k+1)/2}(1/\pi k)\cos(k\pi\beta/2)\cos(kbt)$$

$$+ \sum_1^\infty -\,2\,(-1)^{(k+1)/2}(1/\pi k)\cos(k\pi\beta/2)\cos(kbt)). \tag{47}$$

$$I_1 = EFe^{-at}(\sum_1^\infty -\,2\,(-1)^{(k+1)/2}(1/\pi k)\sin(k\pi w/2)$$

$$\times \sin(kbt/2)$$

$$+ \sum_1^\infty -\,2\,(-\,1)^{(k+1)/2}(1/\pi k)\sin(k\pi\beta/2)$$

$$\times \sin(kbt/2)). \tag{48}$$

$$I_2 = EFe^{-at}(\sum_1^\infty 2\,(-\,1)^{(k+1)/2}(1/\pi k)\sin(k\pi\alpha/2)\sin(kbt)$$

$$+ \sum_1^\infty 2\,(-\,1)^{(k+1)/2}1/\pi k)\sin(k\pi\beta/2)\sin(kbt)). \tag{49}$$

The different series of the eqs. (46) to (49) are either identically the same as some of the already discussed series, or if different their respective curves are obtained by the described method. The complete curves are then obtained as shown for the case of the short-circuited line current.

It has been the author's aim to show that transmission line transients may be computed in a comparatively simple manner by making a slight simplification in the original equations and taking advantage of the known shapes of zigzag curves in terms of Fourier Series. He hopes that other cases of line transients may be treated in a similar manner, thus greatly extending the usefulness of the operational calculus for practical purposes.

Acknowledgment. The author takes this opportunity to acknowledge the previous work and assistance rendered by Messrs. H. C. I. Knutson, J. J. Murphy, D. Rabinow and R. B. Whittredge, all of whom wrote their theses on this subject under Professor Karapetoff's direction; the author's part consisted mainly in coördinating and checking their results. The author also thanks Professor V. Karapetoff who suggested that this article be written.

Notation.

$a = R/2L$, attenuation constant.
$n = (YZ)$, propagation constant.
$Y = (G + pC)$.
$Z = (R + pL)$.
L = inductance per unit length of line.
C = capacitance per unit length of line.
R = resistance per unit length of line.
p = differential time operator d/dt.
1 = Heaviside's Unit Function.
$F = (C/L)^{1/2}$, surge admittance of transmission line.
$I_s = E/Rl$.
l = total length of line.
x = distance along the line.
$u = (l - x)/l$.
$u_1 = 1 - u$.
$\alpha = (l - D + x)/l$, artificial variable.
$\beta = (l - D - x)/l$, artificial variable.
$w = (l + D - x)/l$, artificial variable.
$v = (D - l + x)/l$, artificial variable.
D = distance from shorted end to the applied e.m.f.
E = applied e.m.f.
e = base of Naperian logarithms.
$j = (-1)^{1/2}$.
$m = jn$.
s = any integer.
$k = 2s - 1$.
t = time.
$A_1 = RFl/\pi$.
$A_2 = 2A_1$.

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THE RÔLE OF DISSOLVED GASES IN DETERMINING THE BEHAVIOR OF MINERAL INSULATING OILS.

BY

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Referring to the article by F. M. Clark in this journal 215, No. 1, 39 (1933) on "The Rôle of Dissolved Gases in Determining the Behavior of Mineral Insulating Oils," it is interesting to calculate the diffusion constants predicted by the data contained in Figs. 7, 8 and 9 which refer to the rate of solution of gases in still deaërated transformer oil. In Figs. 7 and 8 are plotted per cent. by volume of air absorbed against hours of exposure. In Fig. 7 the temperature is 25° C., the oil area is 8/10 sq. in. and the oil depth is 11 inches. In Fig. 8 the corresponding values are 80° C., 36 sq. in., and 3¼ inches. It is not stated whether the sides of the vessels used were perpendicular and the bottoms parallel to the oil surface, but we shall assume that they were in what follows.[1] If they were the *per cent.* air absorbed is independent of the surface area, and if they were not, it is in general not a function of surface to depth ratio, but depends upon surface and depth separately in a manner determined by the geometrical form of the vessel, so that Fig. 9 loses its meaning.

If we assume that convection currents are absent, and that we are dealing with pure diffusion, the problem is exactly analogous mathematically to the flow of heat in an infinite slab of thickness d, one face maintained at a given temperature, the other face insulated, and the entire slab initially at zero temperature. The appropriate solution of the corresponding diffusion differential equation

$$\frac{\partial C}{\partial t} = \Delta \frac{\partial^2 C}{\partial x^2}$$

is

$$\frac{C}{C_0} = 1 - \frac{4}{\pi} \sum_{m=0}^{\infty} \frac{1}{2m+1} e^{-(2m+1)^2 \Delta \pi^2 t / 4d^2} \sin^{(2m+1)\pi x/2d},$$

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[1] In a letter Dr. Clark informed me that they were.

where C is the concentration at depth x and time t, C_∞ is the long-time concentration, or solubility, d is the total depth, and Δ is the diffusion constant.

To put this in the form corresponding to Clark's data we must integrate x from 0 to d, giving

$$\frac{\varphi}{\varphi_\infty} = 1 - \frac{8}{\pi^2}\sum_{m=0}^{\infty}\frac{1}{(2m+1)^2}e^{-(2m+1)^2\Delta\pi^2 t/4d^2},$$

where φ and φ_∞ are the percentages of air dissolved at time t and infinity, respectively. This series converges extremely rapidly and allows easy calculation of the data.

If we determine φ_∞ and Δ from the points $t = 20$ and $t = 80$ of Fig. 7 we obtain fair agreement with the rest of the points, a value of $\varphi_\infty = 10.8$ per cent. and a value of $\Delta = 3.3 \times 10^{-4}$ cm.^{2}/sec. A similar calculation for the curves of Fig. 8 gives values of Δ of about 0.02 cm.^{2}/sec.

Since none of the diffusion constants tabulated in I.C.T. depart from 1×10^{-5} by a factor of more than three or four it must be concluded that some convection must have occurred. This is substantiated by the large value of .02 cm.^{2}/sec. at 80° C., which is 100 times its value at 25° C. instead of approximately in the ratio of the square roots of the absolute temperatures as predicted by J. Horiuti.[1] Also the high molecular weight of the oil should cause a *smaller* diffusion constant than that found, for example, in benzol.

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[1] J. Horiuti, *Zs. f. Electrochem.*, **39**, No. 1, 22 (1933).

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

EDWARD WIGHT WASHBURN.

Scientific research suffered a severe loss in the death of Dr. Edward Wight Washburn, chief chemist of the Bureau of Standards, which occurred suddenly at his home in Washington early on the morning of February 6, from heart failure.

During the past two years Doctor Washburn had been a leader in research work on the so-called "heavy water" which is now being studied in almost every chemical laboratory in the world. In fact, he was the first to produce water containing high concentrations of the hydrogen isotope in considerable quantity, by the electrolytic method. He fully realized the significance of this important development and only a short time ago had called attention to the desirability of establishing a central laboratory for the production of heavy water, so that an adequate supply would be available to research workers everywhere. He estimated that such a laboratory could be equipped at a cost not exceeding $25,000 and that the annual expenses would be only $5,000. That important technical and biological developments will result from systematic coöperative investigations in this field seems certain.

Doctor Washburn was born at Beatrice, Nebraska, May 10, 1881. He attended the University of Nebraska and the Massachusetts Institute of Technology, graduating from the latter institution in 1905, and receiving his degree of doctor of philosophy in 1908. He was a research associate in physical chemistry at M. I. T. from 1906 to 1908; associate in chemistry from 1908 to 1910; assistant professor 1910–13, and professor of physical chemistry 1913–16. In 1916 Dr. Washburn became professor of ceramic chemistry and head of the department of ceramic engineering of the University of Illinois and remained in Urbana until 1922. In that year he accepted the editorship of the International Critical Tables published under the auspices of the National Research Council, and in 1926 was chosen by a special committee as the man best fitted for appointment as chief chemist of the Bureau of Standards.

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* Communicated by the Director.

In spite of poor health, Doctor Washburn was extremely active in Bureau affairs. He built up a section of physical chemistry which has carried on many important researches, including fundamental work on the composition of petroleum, a coöperative project with the American Petroleum Institute. As before mentioned, he was the first to produce heavy water in quantity following the discovery of the hydrogen isotope by Urey, Brickwedde, and Murphy in 1932. He was the author of "Principles of Physical Chemistry" published in 1915 and of many research papers, nine having been published in the Bureau's Journal of Research. He was a member of the National Academy of Sciences, National Research Council, American Chemical Society, American Physical Society, American Ceramic Society, Society of Glass Technologists, Washington Academy of Sciences, Sigma XI, and the Illinois Academy of Sciences. He was a fellow of the American Association for the Advancement of Science (chairman of the chemistry section 1923–24), the Royal Society of Arts, and a member of the Cosmos Club of Washington and the Chemists' Club of New York. Dr. Washburn was married in 1910 to Miss Sophie de Veer of Boston, who died two years ago. He left four children.

INFRARED RADIATION FROM EXPLOSIONS IN A SPARK-IGNITION ENGINE.

Observations made through transparent windows in the heads of spark-ignition engines have shown that during an explosion a luminous zone originates at the spark plug and spreads rapidly throughout the combustion chamber until the entire charge is inflamed, the whole mass of gas continuing to glow for some time after flame propagation is complete. Energy is radiated not only in the visible region of the spectrum, but also in the ultraviolet and predominantly in the infrared, the character and intensity of the radiation varying from point to point in the combustion chamber and from instant to instant during the combustion process as a result of the rapid local changes in chemical composition, temperature, and density of the charge.

Using windows of fluorite, transmitting more of the infrared than materials previously used in an engine, measurements have been made at the Bureau with the assistance of the National Advisory Committee for Aeronautics of the variations in intensity and spectral distribution of the radiant energy emitted by the flame at two widely separated points in the engine combustion chamber during normal burning and when fuel knock occurs. Analysis of spectral distributions indicates that the great bulk of the radiation is emitted by water vapor and carbon dioxide. Since these are the final products of the chemical reaction between gasoline and air, variations in the intensity of the radiation indicate the progress of combustion and provide a means of comparing the effects of different engine operating conditions and fuels upon the depth of the reaction zone behind the flame front and the duration of burning in a given element of charge. Thus, reaction appears to reach completion much sooner after inflammation in the portion of the charge involved in fuel knock than in portions burning normally.

TURBULENCE, COMPANION OF REYNOLDS NUMBER

Aeronautical engineers make continual use of the results of tests on small models in wind tunnels in the design of airplanes and airships. In order to apply wind tunnel data, information must be available as to the effects of the size of the model and of the speed on the aerodynamic characteristics. It has long been known that the effects of speed and size are related in that the force coefficients vary with the Reynolds Number, the name given to the product of linear dimension times speed divided by the kinematic viscosity. Much attention has been given to the study of the effect of Reynolds Number.

Another condition to be fulfilled in wind tunnel testing is that the relative motion between the air and the model must be the same as that between the full scale aircraft and the air. This condition can be secured only approximately for there are always small ripples or fluctuations in the wind tunnel air stream. Contrary to expectation, the magnitude of these small fluctuations occurring many times per second, and collectively known as turbulence, influences the aerodynamic characteristics of bodies placed in the air stream. The Bureau, in coöperation with the National Advisory Committee for Aeronautics, has studied methods for measuring turbulence, and for reducing and increasing its magnitude. Studies have also been made of the influence of turbulence on the aerodynamic characteristics of some types of models.

At the request of the editor of the Journal of the Institute of Aeronautical Sciences, a brief paper has been prepared giving a survey of present knowledge of this subject, including an account of the basic phenomenon which is believed to be responsible both for the effect of Reynolds Number and for the effect of turbulence.

SPECULUM METAL CASTINGS.

Castings of speculum metal, composed approximately of one-third tin and two-thirds copper, may be highly polished and have been used for many years as mirrors for optical instruments and for surfaces on which can be ruled the gratings for producing diffraction spectra.

The great telescopes of Sir William Herschel and of Lord Ross employed mirrors made of speculum metal, and contemporary accounts make frequent reference to the extreme difficulty of casting and finishing this alloy. Even today, with many improvements in technique, considerable difficulty is encountered in regular foundry practice in producing a speculum metal casting which has a surface satisfactory for polishing and in which the internal casting stresses are low enough to eliminate the danger of breakage while the casting is cooling in the mold or while it is being polished. It is, therefore, interesting to note that, after considerable experimental work, a new foundry technique, which overcomes these defects, now seems to have been perfected at the Bureau. Further information on this subject may be obtained by addressing the metallurgical division of the Bureau of Standards.

MONOGRAPH ON PURE IRON.

A monograph on pure iron is being compiled at the Bureau in coöperation with the iron alloy committee of the Engineering Foundation. Experimental results on the various properties of iron produced electrolytically and in other ways, and of varying degrees of purity, are scattered throughout German, French, English and other scientific literature. The assembly and critical review of the data from these studies supply the best available information on the fundamental or "base-line" properties of iron from which all the modern engineering uses of steels must be developed by the proper use of alloys with iron and of suitable mechanical and thermal treatments of such alloys.

STRENGTH OF GROUND COAT ENAMELS.

A series of typical ground coat enamels has been under study to determine the effect of changes in composition upon the modulus of rupture in bending. Specimens consisting of drawn rods, somewhat less than 1 mm. in diameter, are supported by fulcrums 2 cm. apart and loaded at the middle. In one schedule each specimen is stressed by increments of 1 kg./mm.^{2} at 15 second intervals until failure. The percentage of specimens failing at and below the respective stresses is plotted against the magnitudes of these stresses, and the stress at which 50 per cent. of the specimens have failed is selected as the strength index of the enamel. In another schedule, each specimen in a group representing a given composition is subjected to a different constant stress, at intervals of 1 kg./mm.^{2} between specimens, and allowed to stand, up to 47 hours. Failures take place with decreasing frequency during the test period and very few failures occur after 24 hours. At each stress between the lowest which caused failure and the highest at which no failure occurred, the stress is plotted against the cumulative percentage of specimens which have failed, calculated by the formula:

$$\frac{F}{N+F} \times 100 = \text{percentage of specimens which have failed,}$$

in which F is the number of specimens failing at and below the given stress and N the number which did not fail at and above it. The stress at which the cumulative percentage of specimens which have failed = 50 is taken as the strength index in this schedule also.

Results indicate a marked effect of the time factor, strength indices in the second test schedule being only about three-fifths as high as those in the first. The changes in the composition studied have less influence than the time factor, but systematic relations between composition and strength have been observed in the results so far obtained. There is an indication that the effect of substituting feldspar for part of the silica and vice versa may not be identical in the two types of test, but it is already apparent that the substitution of boric oxide for sodium oxide, within these composition limits, causes a moderately increased resistance to failure.

REVIVAL OF INTEREST IN LIME FRESCOING.

Some of the most celebrated pictures which have stood for centuries are frescoes on plaster made of lime and sand or marble dust.

Michaelangelo began work on the frescoes in the Sistine Chapel at the Vatican in 1508 and finished in 1512. Thus these frescoes date back to the beginning of American history. The unusual artistic ability of the masters combined with the fact that they considered it necessary to complete the painting the same day the plastering was laid and do the work properly at the first painting—without retouching—may serve to explain why true fresco work has seldom been used in this country. The beautiful frescoes of the Mexican artists, such as Diego Rivera and Jose Clemente Oroszco, have, however, revived the interest in fresco painting in North America. An article in the February, 1933 number of *Scribner's Magazine* entitled, "The Government Recognizes Art," by Suzanne LaFollette, brings forcibly to our attention some of the facts which have recently led to the movement of the Civil Works Administration to employ some 2,500 painters, sculptors, and craftsmen in the decoration of Federal and other publicly-owned buildings. She points out that in a letter to President Roosevelt, George Biddle remarked that Mexico had developed the greatest national school of mural painting since the Renaissance, because President Obregon "allowed Mexican artists to work at plumbers' wages, in order to express on walls of Government buildings the social ideals of the Mexican revolution." Mr. Biddle suggested that American artists be given the same opportunity to express the ideals of their time and country. When, therefore, these suggestions met with the approval of the Administration, and these artists were given a chance to decorate some of the Federal and other publicly-owned buildings, still further impetus was given to the possibilities of the fresco form of decorative art.

Members of the committee in Washington in charge of this phase of the work of the Civil Works Administration came to the Bureau of Standards with the request that these artists be given an opportunity to execute some small panels so that they might better familiarize themselves with the technique involved in frescoing. For many years the Bureau has been making technical investigations of plastering materials and plastering. The Bureau also makes tests on lime, gypsum, and other plastering materials used in the various Government departments, and has coöperated in the establishment of specifications for these materials. The Bureau has been coöperating with these artists in studying the proper mixtures of lime and sand to be used in the frescoing process, together with the best types of these materials for the purpose and the method of their application.

To those who are not particularly familiar with frescoing a brief description of the process may be of interest. In the fresco process of painting, finely divided limeproof pigments suspended in water are applied to the wet plaster. The old masters always applied the fresco painting the same day the plaster was laid. The painter avoided retouching except when absolutely necessary and the whole operation was completed before the plaster had time to dry. What takes place is that the pigments suspended in water partially penetrate into the plaster, and the solution of calcium hydroxide in the plaster during the process of drying is drawn to the surface, surrounds the particles of pigments on the surface and by reaction with the carbon dioxide in the air is converted into calcium carbonate, thus binding the pigments on the surface.

In the fresco process much of the success depends upon having just the right surface in order that the pigments may penetrate into the plaster the proper amount so that the painting may be done most advantageously.

The question has been asked whether or not this process of frescoing is not an expensive one. Except for the work involved in the application of the final coat of plaster and the artist's time, there is no more expense in frescoing than involved in ordinary plastering. The base coats of plaster are applied in much the same way as any ordinary plaster, and it seems logical therefore that more attention should be given to the frescoing of our public buildings at the time they are built, so that upon their completion we may have beautifully frescoed walls. One of the reasons why so many frescoed walls are seen in the public buildings of Europe is that the architects have been giving more consideration to this method of decorating the walls when the buildings were being erected.

WRITING INK FOR PERMANENT RECORDS.

Since the announcement in Technical News Bulletin no. 199, p. 118 (November 1933), of a record ink that seems to have no deteriorating effect upon paper, many requests for more detailed information have been received. In advance of the publication of a paper describing the investigation in which this ink, together with many others, was tested, a short statement seems desirable. The ink that has aroused so much interest is made with a compound known as ammonium ammoniumoxyferrigallate.

Ten years ago Mitchell and Hepworth (Inks, Their Composition and Manufacture, 3d ed., pp. 87–89, 1924) called attention to work done by Silberman and Ozorovitz (*Bull. Soc. Stünte Bucuresti*, vol. 17, pp. 43–57, 1908; and *Chem. Zentr.*, 1908, II, 1024) on compounds obtained from ferric chloride and gallic acid. One of these compounds, ammonium ammoniumoxyferrigallate, $HO . C_6H_2(:O_2 : Fe . ONH_4)CO_2NH_4$ is obtained by mixing solutions of ferric chloride and gallic acid, adding strong ammonia water, and finally precipitating the compound by adding a considerable volume of alcohol. The precipitate after drying is a black, shining brittle mass, which dissolves readily in cold water, yielding an intensely blue-violet solution. The use of a 7 to 8 per cent. solution as writing ink was suggested by the original authors. It becomes insoluble in water within 30 minutes after it is put on paper, and becomes black in a few hours. If it could be prepared by a less expensive method, ammonium ammonium-oxyferrigallate might prove to be a very satisfactory material for the manufacturing of writing ink.

SPONTANEOUS HEATING AND IGNITION OF JUTE.

A number of fires in jute cargoes destined for American ports prompted the initiation of a research to determine the susceptibility of jute to spontaneous heating from microbial growths and from vegetable and animal oils spread over the jute. Tests were conducted with samples ranging in size from a few grams to the 400-pound bale in which the jute fiber is imported.

In the general method of testing adopted, the temperature of the air in the chamber surrounding the sample was maintained a little below that of the sample, after self-heating had begun. The sample was, in effect, thermally insulated, thus approximating the condition which exists for any given portion of the material contained within a larger mass.

No temperatures above 59° C. (138° F.) were obtained due to microbial action, which indicates that no consequential probability exists that ignition can occur from this cause. Only slight heating occurred where the moisture content was initially no higher than 30 per cent. of the weight of the dry jute. Moderate heating developed with initial moisture contents of over 50 per cent. Additions of cultures of microorganisms appeared to accentuate the heating slightly, although for this condition also it was limited by the moisture content.

Self-heating resulting in ignition was obtained consistently with linseed oil and menhaden oil spread on jute and on cotton fiber, starting with initial temperatures in the range 36° to 50° C. (97° to 122° F.). With a drying oil added to linseed oil of amount comparable with that present in prepared paints, ignitions were obtained with initial temperatures no higher than 30° C. (86° F.). No significant difference was noted between jute and cotton fiber in their susceptibility to spontaneous heating with the given oils. The oxidation is primarily of the unsaturated compounds in the oil, the fiber serving to give a large exposed area for the oil film and as material in which ignition can occur after a sufficiently high temperature has been reached.

As a result of methods developed in this work it is now possible, for the first time, to obtain ignitions in almost all trials without the addition of special accelerating agents to the oils. It was found that the factors favoring heating and ignition include optimum percentages of oil to fiber, and thorough coating of the fibers with the oil. The density and size of the sample were also found important, as well as the surrounding temperature and air supply.

The tests were conducted in coöperation with the Bureau of Chemistry and Soils of the Department of Agriculture and loss prevention committee of the Marine Underwriters. A more detailed account of the work will be found in Part II of the *Quarterly* of the National Fire Protection Association for January, 1934.

JOINT MEETING OF INSTITUTE OF RADIO ENGINEERS AND AMERICAN SECTION, INTERNATIONAL SCIENTIFIC RADIO UNION.

Arrangements have been made between the Institute of Radio Engineers and the American Section of the International Scientific Radio Union for a joint meeting in Washington, D. C., annually in the spring. The first joint meeting will be held this year on Friday, April 27. It will be devoted to the presentation of papers on the more fundamental aspects of radio problems. It is thought that this meeting may become an important annual feature of the week which attracts to Washington every year an increasingly large number of scientists and scientific societies.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, WEDNESDAY, FEBRUARY 21, 1934.

The regular monthly meeting of The Franklin Institute was called to order at eight-fifteen o'clock by the presiding officer, Dr. Howard McClenahan, Secretary and Director of the Institute.

It was announced that the Minutes of the previous meeting had been printed in full in the February number of the JOURNAL OF THE FRANKLIN INSTITUTE. Upon motion, it was voted that the Minutes should be approved as printed.

In accordance with the By-laws of The Franklin Institute notice was given at the November meeting of the Institute that amendments to the By-laws would be voted upon at this (February) regular monthly meeting. In accordance with this notification the following amendments were submitted for the approval of the membership of the Institute and upon motion were declared approved: Section IX Museum Memberships: Museum Memberships shall consist of two classes.

(*a*) Family Membership: Such memberships extend unlimited admissions to the museum and the planetarium to all persons who are named as members of the household by the person paying the fee. Individual cards of admission will be sent to the persons so named. The fee is twenty dollars per year.

(*b*) Individual Memberships: Such memberships extend unlimited admission to the museum and the planetarium to an individual who pays a fee of ten dollars per year.

Old Section IX now becomes—Section X privileges: All members of whatever classes, except Museum Members are entitled to participate in the meetings of the Institute etc. (Rest of this Section remains the same.)

The presiding officer then stated that these amendments would be made and would thereafter constitute a regular part of the By-laws.

The Secretary announced the following changes in membership since last month: seven new Resident Members; two Non-Resident Members; nine Student Members; and under the new Museum Membership: forty Family Members and fifty-three Individual Members.

The Secretary also stated that on Friday evening, February twenty-third, the Library would be formally opened and Pepper Hall would be dedicated. The members of the Institute, members of the Poor Richard Club, and the general public were cordially invited to attend.

He announced that on Monday evening, February twenty-sixth, The Franklin Institute would celebrate the one hundredth anniversary of the organization of its Committee on Science and the Arts by a subscription dinner and a play reënacting the first meeting as it was held on February 26, 1834. He announced that invitations had been sent out to all members of the Institute.

Announcement was made of the following appointments of Institute Committees by the President for the year 1934 and the election of the following members of the Committee on Science and the Arts as indicated:

COMMITTEES OF THE INSTITUTE.

Committee on Library.

Mr. C. W. Bates
Dr. H. J. M. Creighton
Mr. W. G. Ellis
Mr. F. Lynwood Garrison
Mr. C. A. Hall
Dr. J. S. Hepburn
Dr. G. A. Hoadley
Mr. L. F. Levy
Mr. T. S. Rowland
Dr. W. T. Taggart

Committee on Meetings.

Dr. James Barnes
Dr. George S. Crampton
Dr. T. G. Delbridge
Mr. W. H. Fulweiler
Dr. A. W. Goodspeed
Dr. H. McClenahan
Mr. Charles Penrose
Dr. G. D. Rosengarten
Mr. James G. Vail
Mr. W. C. Wagner

Committee on Science and the Arts.

(Following Members reëlected to serve three years.)

Dr. James Barnes
Mr. Charles E. Bonine
Dr. G. H. Clamer
Dr. H. J. M. Creighton
Mr. William C. Cushing
Mr. Samuel B. Eckert
Dr. Hiram B. Ely
Mr. Benjamin Franklin
Mr. Walter H. Fulweiler
Mr. Charles D. Galloway
Mr. Clarence A. Hall
Dr. Joseph S. Hepburn
Mr. John B. Klumpp
Mr. William N. Jennings
Mr. Lionel F. Levy
Mr. H. H. Quimby
Mr. Coleman Sellers, 3d
Mr. James Stokley

(Following members elected to serve three years.)
Dr. T. G. Delbridge
Mr. Edward Forstall

(Following member elected to serve two years.)
Mr. Joseph Winlock

There being no further business, the Secretary introduced as the speaker of the evening, Dr. A. W. Hull, General Electric Company, Schenectady, New York, who spoke on the very important subject of "Fundamental Phenomena in Thyratrons."

The meeting was adjourned by a rising vote of thanks to Dr. Hull for his very full paper, at nine-forty P.M.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, February 14, 1934.*)

HALL OF THE COMMITTEE,
PHILADELPHIA, FEBRUARY 14, 1934.

MR. THEOBALD F. CLARK *in the Chair.*

The following reports were presented for final action:

No. 2974: Vertical Antenna for Radio Transmission.

This report recommended the award of the Elliott Cresson Medal to Mr. Stuart Ballantine, of Boonton, New Jersey, "In consideration of his contributions to our knowledge of design principles for electromagnetic radiating structures resulting in greatly improved effectiveness for frequencies now being employed for radio broadcasting."

No. 2977 }
No. 2978 } The Standing Committee on The Franklin Medal presented its report for final action making the following recommendations:

"That two Franklin Medals be awarded this year, one to

"DOCTOR HENRY NORRIS RUSSELL, of Princeton, New Jersey, 'In recognition of his diversified and brilliant contributions to scientific knowledge in the field of astronomy and astro-physics, particularly pioneer work in the application of physical theories to astronomical problems, and his researches on stellar constitution and evolution';

"And the other to

"DOCTOR IRVING LANGMUIR, of Schenectady, New York, 'In recognition of his numerous and fundamental researches in chemistry and physics, especially his work in the domain of surface chemistry, and of the many benefits bestowed on modern civilization through the results of his investigations.' "

The following reports were presented for first reading:

No. 2979: Improved Metal Floor Construction.
No. 2981: Literature.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting Board of Managers, February 21, 1934.*)

RESIDENT.

MR. RAYMOND G. BOGARDUS, Wire Rope Salesman, John A. Roebling Son's Company, Philadelphia, Pa. For mailing: 117 Lincoln Avenue, Manoa, Pa.

MR. RUSSELL P. HEUER, Chemical Engineer, General Refractories Company, Philadelphia, Pa.

MR. WILLIAM J. KASSIMIR, Instrument Mechanic, Atlantic Refining Company, For mailing: 3908 North Seventh Street, Philadelphia, Pa.

MR. KNUT AXEL KRIEGER, Assistant in Chemistry, Harrison Laboratory, University of Pennsylvania, Philadelphia, Pa.

MR. MORRIS A. LINTON, President, Provident Mutual Life Insurance Company, Philadelphia, Pa. For mailing: Moorestown, N. J.

MR. RALPH F. SCHOLL, Mechanic, Atlantic Refining Company, Philadelphia, Pa.

NON-RESIDENT.

MR. HARVEY FLETCHER, Research Engineer, Bell Telephone Laboratories, New York City.

PROF. MILTON CALEB STUART, Professor of Mechanical Engineering, Lehigh University, Bethlehem, Pa.

STUDENT.

MR. ALBERT ACKOFF, 602 East Wensley Street, Philadelphia, Pa.

MR. THOMAS CAMPBELL BAGG, 5024 Walton Avenue, Philadelphia, Pa.

MR. BURTON J. CHERNEY, 1234 North Sixteenth Street, Philadelphia, Pa.

MR. BERNARD J. KLEIN, 617 South Fifty-seventh Street, Philadelphia, Pa.

MR. ISADORE D. LONDON, Student, Temple University. For mailing: 5652 Arlington Street, Philadelphia, Pa.

MR. REED W. MALCOLM, Student, Central High School. For mailing: 1911 North Camac Street, Philadelphia, Pa.

MR. JAY MEIER, 3519 Kensington Avenue, Philadelphia, Pa.

MR. BERNARD JAY PLONE, Student, University of Pennsylvania. For mailing: 224 Highland Avenue, Barrington, N. J.

MR. HENRY A. SLOVITER, Student, Temple University. For mailing: 868 North Forty-fifth Street, Philadelphia, Pa.

MUSEUM MEMBERSHIP, FAMILY.

Mr. Charles G. Berwind, Commercial Trust Building, Philadelphia, Pa.
Mr. C. M. Clark, Sixteenth and Locust Streets, Philadelphia, Pa.
Mr. Norbert A. Considine, Paper House of Pennsylvania, 28 North Sixth Street, Philadelphia, Pa.
Mr. Franklin S. Edmonds, 1418 Packard Building, Philadelphia, Pa.
Mr. Harold Evans, 1935 Commercial Trust Building, Philadelphia, Pa.
Mr. William B. Griscom, Abbotts Dairies Inc., Thirty-first and Chestnut Streets, Philadelphia, Pa.
Mr. Frazer Harris, "Harston," Chestnut Hill, Pa.
Mr. John V. Hastings, Jr., 819 Filbert Street, Philadelphia, Pa.
Mr. Victor A. Hemphill, 114 South Front Street, Philadelphia, Pa.
Mr. John B. Heyl, Ardmore, Pennsylvania.
Miss Alice G. Howland, Shipley School, Bryn Mawr, Pa.
Mr. G. T. Kellner, 127 South Fifth Street, Philadelphia, Pa.
Mr. C. Albert Kuehnle, 2112 Sansom Street, Philadelphia, Pa.
Mr. H. Gates Lloyd, Jr., P. O. Box 1586, Philadelphia, Pa.
Mr. Stacy B. Lloyd, Seventh and Walnut Streets, Philadelphia, Pa.
Mr. C. T. Ludington, Fidelity-Phila. Trust Building, Philadelphia, Pa.
Mrs. Edgar Allan Poe, Garrison, Maryland.
Dr. C. Fred Rau, Rydal, Pennsylvania.
Mr. B. B. Reath, 127 South Fifth Street, Philadelphia, Pa.
Mr. Howard S. Roberts, 4238 Spruce Street, Philadelphia, Pa.
Mr. Walter E. Sweeting, 4015 Walnut Street, Philadelphia, Pa.
Mr. Harry C. Tily, 2d, 801 Market Street, Philadelphia, Pa.
Mr. Charles A. Tyler, 600 Chestnut Street, Philadelphia, Pa.
Mrs. Edward F. R. Wood, Seventeenth and Sansom Streets, Philadelphia, Pa.
Mr. Richard D. Wood, 514 Walnut Street, Philadelphia, Pa.
Mr. R. Francis Woods, Jr., 127 South Fifth Street, Philadelphia, Pa.
Mrs. Charles C. Wriggins, 470 Locust Avenue, Germantown, Philadelphia, Pa.

INDIVIDUAL.

Mr. M. Alpern, American Engineering Company, Cumberland and Aramingo Avenues, Philadelphia, Pa.
Mr. Add B. Anderson, Board of Public Education, Parkway at Twenty-first Street, Philadelphia, Pa.
Miss Lida H. Ashbridge, Rosemont, Pa.
Miss Caroline D. Bache, 1711 Rittenhouse Street, Philadelphia, Pa.
Mr. John Hampton Barnes, Devon, Pa.
Miss Eleanor Bartol, Green Hill Farms, Overbrook, Pa.
Mr. D. M. Bates, 112 North Broad Street, Philadelphia, Pa.
Mrs. Edward Bok, Merion, Pa.
Mr. Henry D. Breyer, Jr., Forty-third Street and Woodland Avenue, Philadelphia, Pa.
Mr. Joseph H. Bromley, Jr., 1021 West Upsal Street, Germantown, Philadelphia, Pa.
Mrs. Edward Browning, 306 South Nineteenth Street, Philadelphia, Pa.
Mr. Miers Busch, 1006 Spruce Street, Philadelphia, Pa.

Mrs. Edgar H. Butler, 21 West Sunset Avenue, Chestnut Hill, Philadelphia, Pa.
Miss Elizabeth B. Chew, "Clivenden," Germantown, Pa.
Mr. Jay Cooke, 2d, 1428 Chestnut Street, Philadelphia, Pa.
Mr. James Francis Cooke, Presser Foundation, 1712 Chestnut Street, Philadelphia, Pa.
Mrs. Alexander Brown Coxe, Paoli, Pa.
Mr. Nicola D'Ascenzo, 1602 Summer Street, Philadelphia, Pa.
Mrs. James Mapes Dodge, 5000 McKean Avenue, Germantown, Pa.
Mrs. George L. Estabrook, 620 West Cliveden Avenue, Germantown, Pa.
Mr. Stanley G. Flagg, Bryn Mawr, Pa.
Mrs. Stanley G. Flagg, Bryn Mawr Avenue, Bryn Mawr, Pa.
Mr. Frank B. Foster, 1911 Franklin Trust Building, Philadelphia, Pa.
Mr. Herbert W. Goodall, 1420 Walnut Street, Philadelphia, Pa.
Mr. C. Warren Hooven, c/o Mrs. Edward Bok, Merion, Pa.
Mr. Hubert J. Horan, 416 Bourse Building, Philadelphia, Pa.
Dr. Bernard Kohn, 1516 North Fifteenth Street, Philadelphia, Pa.
Mrs. Isadore Kohn, 1517 North Sixteenth Street, Philadelphia, Pa.
Miss Anne Irwin Laughlin, "Greylock," Chestnut Hill, Pa.
Miss Mary A. Leal, 1827 South Broad Street, Philadelphia, Pa.
Mr. Richard W. Lloyd, Haverford, Pa.
Mr. William L. McLean, Jr., 202 Bulletin Building, Philadelphia, Pa.
Mrs. Herman Loeb, Warwick Hotel, Philadelphia, Pa.
Mrs. John W. Pepper, Jenkintown, Pa.
Miss Heln P. Read, 3917 Walnut Street, Philadelphia, Pa.
Dr. David Riesman, 1520 Spruce Street, Philadelphia, Pa.
Mr. G. Brinton Roberts, 1416 Chestnut Street, Philadelphia, Pa.
Mr. Benjamin Rush, 1600 Arch Street, Philadelphia, Pa.
Dr. George deSchweinitz, 1705 Walnut Street, Philadelphia, Pa.
Mr. William Percy Simpson, 1611 Penna. Building, Philadelphia, Pa.
Mr. Joseph F. Stockwell, Keystone Telephone Company, 135 South Second Street, Philadelphia, Pa.
Mr. Albert H. Smith, 127 South Fifth Street, Philadelphia, Pa.
Miss Mabel L. H. Thomas, Bryn Mawr, Pa.
Miss Helen B. Tyler, Villanova, Pa.
Mr. Paul T. Warner, 6832 Wayne Avenue, Philadelphia, Pa.
Miss Hepsey Norris Wells, 1112 Wallace Street, Philadelphia, Pa.
Mrs. William White, Haverford, Pa.
Mr. Hamilton M. Wilson, 5653 North Tenth Street, Philadelphia, Pa.
Mrs. Albert Wolf, 250 South Seventeenth Street, Philadelphia, Pa.
Mrs. Benjamin Wolf, 250 South Seventeenth Street, Philadelphia, Pa.
Mr. Graham Wood, 512 Walnut Street, Philadelphia, Pa.
Miss Josephine T. Woolman, 121 Glenn Road, Ardmore, Pa.

CHANGES OF ADDRESS.

Mr. Alfred Cook, Roselawn Avenue, Lansdowne, Pa.
Mr. Glendon J. Dunlap, 126 Capitol Avenue, Hartford, Conn.
Mr. E. G. Eberle, 2215 Constitution Avenue, Washington, D. C.
Mr. Armin Elmendorf, 24 Ave Huart-Hamoir, Brussels, Belgium.

MR. MAYO D. HERSEY, Division of Engineering, Brown University, Providence, R. I.
MR. W. N. JENNINGS, 1034 Arch Street, Philadelphia, Pa.
MR. LUCIEN E. PICOLET, 331 South Twelfth Street, Philadelphia, Pa.
MR. C. H. QUINN, 1121 Pacific Mutual Bldg., Los Angeles, Calif.
MR. ROBERT RIDGEWAY, 24 Gramercy Park, New York, N. Y.
MR. G. N. SIEGER, c/o S-M-S Corporation, 1165 Harper Avenue, Detroit, Michigan.
MR. A. D. W. SMITH, 32d Floor, Lewis Tower Bldg., Philadelphia, Pa.

NECROLOGY.

Rear Admiral R. T. Hall, U.S.N., Wynnewood, Pa.
Mr. T. Chalkley Hatton, Milwaukee, Wis.
Colonel Royal Mattice, Philadelphia, Pa.
Mr. LeGrand Parish, Mountain View, N. J.
General John Pitman, Orange, N. J.
Mr. S. D. Smith, Philadelphia, Pa.

LIBRARY NOTES.

RECENT ADDITIONS.

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BOOK REVIEWS.

FUNKTIONENTAFELN MIT FORMELN UND KURVEN, von Dr. Eugen Jahnke, und Fritz Emde, 330 pages, tables, illustrations, 16.5 × 24.5 cms. Leipzig und Berlin, Verlag und Druck von B. G. Teubner, 1933. Price 16 marks.

Since the introduction of the First Edition of the Tables of Functions in 1909, this work has experienced a steadily increasing demand by mathematicians, physicists, engineers and other scientific workers. The volume is intended to deal mainly with the higher functions. The authors have intentionally striven to be as practical as possible in that they have maintained a widened scope rather than sacrifice space to the attainment of extreme accuracy. The book is plentifully supplied with references to specific articles should the worker desire to pursue any subject more intensively. The authors have been generous with graphs and relief diagrams. These latter are especially valuable in that they give the investigator a very complete concept of a function's significance which he could not otherwise acquire except by a laborious system of calculation and visualization. This Second Edition contains many improvements over its predecessor. Spherical harmonics of the second kind and the associated spherical harmonics have been added to the section and are represented by curves. The section of Bessel functions has been greatly extended. The Nielsen definition of the functions of the second and third kind is now uniformly introduced throughout all the tables. Riemann's Zeta function has been included.

In recognition of the widespread use this volume enjoys, the text has been written in English as well as in German.

T. K. CLEVELAND.

THE PHYSICS OF ELECTRON TUBES, by L. R. Koller, Ph.D., Research Laboratory, General Electric Company, 205 pages, illustrations, 15 × 23.5 cms. New York, McGraw-Hill Book Company, Inc., 1934. Price $3.00.

This is a book for which a niche has been waiting. To date, much of an easily assimilable nature has been written upon electron tube circuits which represent the more practical aspects of the subject and many highly specialized investigations dealing with phenomena inside the tube have been conducted and published from time to time. Now, L. R. Koller has taken all such data dealing with the internal phases of electron tube operation, correlated and re-presented them in the shape of a readily understandable textbook. This volume should be much desired by the student of physics and engineering; to the technician who knows how electron tubes work and often wonders why they work; to both the research student and the inventor who should glean a number of helpful and stimulating ideas from such a smoothly running narrative of this kind.

As just intimated, the book deals with its subject in a logical sequence which is much appreciated by the serious reader in that such a presentation appears to lessen the effort almost always required for the assimilation of scientific facts. From a short discussion on the Theory of Thermionic Emission, the author passes to the fundamental subject of Thermionic Emitters which includes the well known thoriated tungsten, the oxide-coated and the cæsium cathodes. The phenomena of secondary emission is discussed and a number of practical applications described. Of course a relatively high temperature and a good vacuum are fundamental to the successful operation of these tubes so that methods of determining the first and insuring the second receive due consideration. Space Charge and Discharges in Gases are both important factors in electron tube operation and serve as introductory topics to the chapter on Grid-Controlled Arcs.

The chapters on Photoelectricity, Photoconductivity and the Photovoltaic Effect are particularly informative and illuminating. A very interesting practical application of the photovoltaic effect has recently appeared in the form of a direct reading meter for measuring intensities of illumination. At the end of each chapter there is a list of references directing the reader to supplementary material. Under Appendix headings will be found special treatment of Richardson's Equation, the Schottky Equation and the Derivation of the 3/2 Power Law for Coaxial Cylinders. The book terminates with a series of problems classified according to the chapters.

T. K. CLEVELAND.

DIFFERENTIAL EQUATIONS FOR ELECTRICAL ENGINEERS, by Philip Franklin, Associate Professor of Mathematics, Massachusetts Institute of Technology, 299 pages, illustrations, 14.5 × 22.5 cms. New York, John Wiley & Sons, Inc., London, Chapman & Hall, Ltd., 1933. Price $2.75.

Have any of your readers a desire to augment your knowledge of calculus, particularly with the kind designed to aid the student of electrical engineering? If so, this may be the book you are seeking. According to the author, the text represents the substance of a course given for over ten years to electrical engineering students in their juinior year at the Massachusetts Institute of Technology. Even at that, the subject matter is presented on the assumed basis that the reader has had no previous training other than the ordinary first course in calculus.

The author, in his preface, points out that: "The first three chapters are concerned with the ordinary differential equations which arise in the problem of determining the flow of current in a network with lumped constants, and such formal knowledge of complex numbers and Fourier series as is useful for their convenient solution."

"The object of the next three chapters is to give the reader an elementary working knowledge of partial differential equations, including their mathematical origin, geometric and physical meaning, and solution for assigned boundary values."

"The last two chapters are of a more theoretical nature, containing demonstrations which justify the earlier calculations with power series and Fourier series."

A very attractive feature is the practice of inserting sets of problems directly following each special subject of the text. These should prove to be of inestimable aid when the book is used for home study. Needless to say, the answers will be found at the end, sandwiched between the Bibliography and the Index.

T. K. CLEVELAND.

MANUFACTURE OF SODA, WITH SPECIAL REFERENCE TO THE AMMONIA PROCESS. By Te-Pang Hou, Ph.D. American Chemical Society Monograph No. 65. With 129 tables and 72 illustrations. 15.5 × 23.5 cm. New York, The Chemical Catalog Co., Inc., 1933. Price $8.00.

Inspiring literature is not commonly to be sought in prefaces to technological monographs. Dr. Hou has written well and usefully, however, his prefatory remarks reflecting both experience and contemplation in the service of chemical industry. They are commended particularly to chemists and chemical engineers lacking industrial experience.

This is believed to be the first book in the English language which covers the soda industry in such a manner. The age-long secretiveness in the alkali industry is herein dispelled by as detailed an account as is practicable of the various operations which enter the soda industry. Separate chapters are given to the burning of limestone (26 pages), the ammoniation of saturated brine (18 pages) and so on for the unit operations. The book has been written primarily from the viewpoint of the plant operator although as the author says in the preface, "Such a book as this cannot be meant to take the place of the services commonly rendered by an alkali designer or consulting expert." It would seem that the industry still has some tricks up its sleeve. Nevertheless in a true spirit of helpfulness to the managers of such plants, the most trivial detail of operation is seemingly never overlooked.

The manufacture of soda represents a large scale chemical industry extending over a long period of time. Students of chemical engineering, especially those historically minded, will find much in this volume to warrant their earnest attention for the soda industry perhaps as much as any other has contributed to the development of methods and operations today known as unit processes. There are excellent summaries of the development of the Le Blanc and the Solvay processes with dates and names and statistics in abundance.

Numerous examples worked out in detail are included, such for example as the calculation of the theoretical percentage of coke required and the percentage of CO_2 in the gas obtained in the burning of limestone.

Sodium carbonate is naturally the principal product of the soda industry. Other products dealt with include refined bicarbonate, caustic soda by both the ash and the electrolytic processes, sodium carbonate monohydrate, sal soda, sodium sesquicarbonate, refined salt, ammonium chloride, ammonium carbonate, calcium chloride, calcium sulphate, lime, chlorine, bleaching powder and synthetic hydrochloric acid.

The book is written in excellent English although it could be more concise. This could be achieved partly by a general plant flow diagram against which the description could be largely built up. Such a drawing would be a most valuable addition, conserving both the time and patience of the reader who if unacquainted with the industry very shortly finds himself entangled in a maze of operations and equipment the relationships of which are not easy to keep clear.

Good chapters are included on special requirements of the industry and on the detailed chemical analyses and tests used. The latter chapter should be of interest to consumers of the respective products. The last chapter on layout and design of the ammonia soda plant is one which may excite considerable controversy, but the author is to be commended for courage in his attempt. The reviewer feels that the book is generally well done and a worthy addition to the A. C. S. Monographs.

LESLIE R. BACON.

THE HEROIC AGE OF SCIENCE, THE CONCEPTION, IDEALS, AND METHODS OF SCIENCE AMONG THE ANCIENT GREEKS, by William Arthur Heidel, 200 pages, 15.5 × 23 cms. Baltimore, The Williams and Wilkins Company, 1933. Price $2.50.

This book, publication No. 422 of the Carnegie Institution of Washington explores a relatively deserted field of scientific investigation. The author as Research Professor of Greek Language and Literature in Wesleyan University, is well equipped to lead us by the hand to the ancients and to introduce a sophomoric world to the Greek masters. Just how much these former philosophers have to do with the revelations of science in its present nakedness is exceedingly difficult to determine. W. A. Heidel should be thanked for crediting Strabo, Hesiod, Plato, Hippocrates, Herodotus, Hecataeus and Aristotle (not to mention all the others) with their share in establishing some of the bases of science.

The book is not easy to read. It does repay and it does reveal the lustre of the Greek mind, that marvel of the ages which led to adventure, to research and into the vaulted galleries of imagination. I hear again the tribute of Andrew Lang:

"So gladly from the songs of modern speech
Men turn, and see the stars, and feel the free
Shrill wind beyond the close of heavy flowers,
And through the music of the languid hours
They hear like Ocean on a western beach
The surge and thunder of the Odyssey."

H. W. ELKINTON.

THE ROMANCE OF RESEARCH, by L. V. Redman, Vice-President and Director of Research, Bakelite Corporation, and A. V. H. Mory, Associate Director of Research, Bakelite Corporation, 149 pages, 13 × 19 cms. Baltimore, The Williams and Wilkins Company, 1933. Price $1.00.

Here is another book of the Century of Progress Series. A tidy volume of 149 pages constructed to give him who runs something to read. It spreads before the uninitiated the point of view of research, examining past growth and anticipating the future. The part played by materials and particularly the development of new materials in present day industry has an important part in the book.

The most useful section of the book treats with the relation of investment to invention. To any entrepreneur and especially to a small business with limited resources, this is a very pressing problem—when to persevere with productive research and when to drop it like a hot potato.

On the fly leaf lies, as so frequently, the key thought:—"The time will come when careful study through long ages will bring to light the secrets of Nature."—Seneca.

H. W. ELKINTON.

NATIONAL RESEARCH COUNCIL, BULLETIN NO. 90—Physics of the Earth—VI, Seismology, 223 pages, illustrations, tables, 17 × 25 cms. Washington, National Research Council of the National Academy of Sciences, 1933. Price $2.50.

Twenty papers make up this cover, all treating with earthquakes, causes, effects and behavior. These papers are written by authorities in this interesting field of terrestrial physics. Such names as J. B. Macelwane, H. O. Wood, H. F. Reid, J. A. Anderson and P. Byerly, sign respective chapters.

The difference between tectonic and volcanic quakes is brought up to date by Macelwane and Wood in Chapters Two and Three. One interesting subdivision of quakes, namely those due to rock falls and impacts (Chapter Five), is to be dismissed according to Macelwane if it were not for the controversies that have raged. The theory of Volger, who held that the entire mountain system of the Alps is supported on gigantic vaults over immense caves miles in diameter, with occasional rock falls and consequent earthquakes, is one of the most grotesque theories. A seismologist with marine tendencies can find satisfaction in the study of another interesting group of disturbances, the quakes of the ocean floor, with their catastrophic effects on the adjacent shores.

The subject is not spared its highly technical features which to another quakist should be positively entertaining. To the unlucky Yankee who stood in the streets of Managua during the severe earthquake that recently reduced that city, I am not so sure of a reception. That poor fellow had other things to think of when the quake spared one leg entirely, but twisted the other so violently that it snapped the bone.

One must not be diverted from the serious observations of seismology by superficial freaks of nature. In fact it is well to remember that earthquakes are one of the few remaining acts of God not yet captured by an understanding science. Even here the empire of man is extending inch by inch so that two marvels will soon be secure: one, men will understand the laws of earthquakes better, and two, we may be able to anticipate bad earthquakes. A warning of ten, five, or even one minute would result in a great saving of human life. Seismology is a very important science.

Such benefits are had as a result of tireless and exhaustive study as recorded in Physics of the Earth—VI, previous volumes of which series are known to the readers of the JOURNAL.

H. W. ELKINTON.

THE BOOK OF THE STAINLESS STEELS, edited by Ernest E. Thum, Editor of *Metal Progress*. 631 pages, 15 × 23.5 cms. Cleveland, American Society for Steel Treating, 1933.

For such an ambitious undertaking this book carries but a modest title. It might have been called "The Book of Knowledge of Stainless Steels." The aggregate experience here recorded, largely practical, is enormous. The contents are divided into four parts, respectively, I—Production and Fabrication, II—Properties of the Typical Alloys, III—Requirements of the Consuming Industries, IV—Classification and Index. Part I comprises eight chapters and 204 pages and is the work of thirty authorities from representative manufacturers and research laboratories. Part II carries eight chapters also and is likewise a combination of papers. Part III consists of six chapters dealing with such subjects as testing methods, special requirements of the chemical and food industries, the metallurgical industries, architectural applications, uses in the transportation industries and in the power industries. Part IV consists of a very useful compilation of corrosion and heat resisting alloys, their trade names and manufacturers, comprising 14 pages.

Editor Thum has done a commendable job in assembling a group of papers which cover practically every phase of the manufacture, properties and uses of the so-called stainless steels. There are many evidences of close editing aside from high typographical perfection. The value of the individual papers is frequently enhanced by editorial notes or references to other papers where related subject matter is taken up. Numerous differences of opinion representing the views of the individual contributors are usually cross-referenced. It cannot be said that all the papers are of equal merit or of equal importance but a high standard is generally maintained. A single author might cover the same material more concisely but no individual could do it so thoroughly.

The Book of Stainless Steels is recommended to all having serious interests in that subject, and indeed to those having merely casual interests in the general metallurgy of steels and their fabrication into useful forms. Much light thereon is directly reflected by the general editorial policy of assuming a knowledge of the carbon steels and basing the discussion of the stainless steels on the differences exhibited.

The book is well illustrated and excellently printed but might perhaps be worthy of a somewhat stronger binding.

LESLIE R. BACON.

PUBLICATIONS RECEIVED.

Chemical Patent Index, a comprehensive and detailed index of the subject matter of specification and claims of United States patents and patent reissues granted . . . 1915–1924, by Edward Chauncey Worden, First, volumes 3 and 4. 17 × 25 cms. New York, The Chemical Catalog Company, Inc., 1933. Price $25.00 each.

College Physical Science, an Orientation Course, by Paul McCorkle, and J.

Arthur Lewis, 327 pages, illustrations, 15 × 22 cms. Philadeplhia, P. Blakiston's Son & Company, Inc., 1934. Price $2.00.

Physical Optics, by Robert W. Wood, third edition, 846 pages, illustrations, 14.5 × 22.5 cms. New York, The Macmillan Company, 1934. Price $7.50.

Industrial Radiography, by Ancel St. John and Herbert R. Isenburger, 232 pages, illustrations, 15 × 23.5 cms. New York, John Wiley & Sons, Inc., London, Chapman & Hall, Ltd., 1934. Price $3.50.

Easily Interpolated Trigonometric Tables with Non-Interpolating Logs, Cologs and Antilogs, No. 6A and 7 of the Simplified Series, by Frederick W. Johnson, 2 volumes, 17.5 × 24.5 cms. San Francisco, The Simplified Series Publishing Company, 1933. Price, No. 6A, $1.85; No. 7, $3.50.

A First Book in Chemistry, by Robert H. Bradbury, third edition, 633 pages, illustrations, 13.5 × 21 cms. New York, D. Appleton-Century Company, Inc., 1934. Price $1.80.

Elements of Hydraulic Power Generation, by Arthur M. Greene, Jr., 58 pages, illustrations, 15 × 22.5 cms. New York, John Wiley & Sons, Inc., London, Chapman & Hall, Ltd., 1934. Price $1.00.

International Hydrographic Bureau, Year-Book, 1934, 83 pages, 13.5 × 18.5 cms. Monaco, Hydrographic Bureau, 1934.

Ontario Department of Mines, Forty-Second Annual Report, three parts, 16.5 × 25 cms. Toronto, King's Printer, 1933. Bulletin No. 80, Money and the World Crisis, by H. S. Denny, 34 pages, 16.5 × 25 cms. Toronto, King's Printer, 1933. Bulletin No. 89, Mineral Production of Ontario, by W. R. Rogers and A. C. Young, 8 pages, tables, 16.5 × 25 cms. Toronto, King's Printer, 1933. Bulletin No. 90, Final Summary of Mineral Statistics for 1932 and Metal Production of Ontario for the First Nine Months of 1933, by W. R. Rogers and A. C. Young, 8 pages, tables, 16.5 × 25 cms. Toronto, King's Printer, 1933.

National Advisory Committee for Aeronautics, Technical Notes: No. 485, A Comparison of Several Methods of Measuring Ignition Lag in a Compression-Ignition Engine, by J. A. Spanogle, 10 pages, illustrations, 20 × 26 cms. Washington, Committee, 1934. No. 486, The Effect of Trim Angle on the Take-Off Performance of a Flying Boat, by James M. Shoemaker and John R. Dawson, 15 pages, illustrations, 20 × 26 cms. Washington, Committee, 1934. No. 487, Tests of Three Tapered Airfoils Based on the N. A. C. A. 2200, the N. A. C. A.—M6, and the Clark Y Sections, by Raymond F. Anderson, 8 pages, illustrations, 20 × 26 cms. Washington, Committee, 1934. No. 488, A Complete Tank Test of a Flying-Boat Hull with a Pointed Step—N. A. C. A. Model No. 22, by James M. Shoemaker, 15 pages, illustrations, 20 × 26 cms. Washington, Committee, 1934.

CURRENT TOPICS.

How the Vitamins Shall Be Advertised.—(*Chem. and Ind.*, Vol. 53, p. 53.) While many food and drug manufacturers in this country are somewhat heatedly discussing the proposed revisions to the Federal Pure Food and Drug Regulations, the Swiss have enacted a law regulating the manner in which vitamin preparations shall be advertised. The Swiss Government Department of Health recognizes how essential to a person's health and well-being are the vitamins when taken in sufficient and carefully regulated quantities. They also realize how susceptible the public can be to the exploitation of such preparations especially where they are something directly concerned with the individual's health.

Unlike most food and drug preparations which can be analyzed with comparitive ease, some vitamin preparation of allegedly high content may have been diluted to give a dose that is practically worthless. The present recognized methods for testing vitamins are rather tedious and intricate so that the ordinary food analyst is hardly in a position to conduct the check ups upon all such proprietary preparations. Thus, only since the International Conference in June, 1931 have there been established standards and units for four of the vitamins, namely the fat-soluble vitamin-A, the antirachitic vitamin-D, the antineuritic vitamin-B, and the antiscorbutic vitamin-C. The reference standards for this purpose are respectively carotene, a solution of irradiated ergosterol prepared according to a definite prescription, an extract of rice polishings adsorbed on fuller's earth and fresh lemon juice. The tests are further complicated by the fact that living animals may vary in their responses to identical conditions and such animals should be from stock reared on a diet of definite composition.

In order to protect the people, the food regulations as far back as 1930 were revised to the effect that no food can be put on sale with a mention of a particularly high vitamin content except after authorization by the Cantonal authority; such authorization being based on the issuance of a certificate testifying to the accuracy of the manufacturers claims. In order to repress further many probable advertising abuses the Federal Department of the Interior will put in force on June 30, 1934, instructions as to how foods containing vitamins shall be labelled, described and advertised, after which no other form of descriptive matter will be allowed.

Thus, if permission has been given to indicate a particularly high vitamin content, it is permissible to make statements on the advertising matter of a general character on the nature and action of these substances. For example, (1) that vitamins, together with the nutritive substances (fats, proteins, carbohydrates, mineral salts) are essential for a rational diet, and that their absence can provoke certain organic troubles known as avitaminosis or deficiency diseases as typified by rickets in man; (2) that it is essential in particular to provide infants with a sufficient dose of all the vitamins; (3) that actually among the substances known as vitamins, the following have been recognized as indispensable for man. The anti-xerophthalmic vitamin-A, the antiberi-beri vitamin-B_1, the anti-pellagra vitamin-B_2, the antiscorbutic vitamin-C and the antirachitic vitamin-D.

If a particular high content of vitamin-A has been stated it may be mentioned that this vitamin is necessary for normal growth of the body and that its absence lessens the resistance of the organism to infections.

For vitamin-B_1 . . . that this vitamin is necessary for the normal growth of the body and the normal assimilation of carbohydrates (sugar and starch) by the organism; that its absence can provoke lack of appetite and that it contributes to the maintenance of the normal function of the nervous system (but not that it protects against nerves).

For vitamin-B_2 . . . that this vitamin is necessary for the normal growth of the body and for the normal functions of the nervous system and the digestive organs.

For vitamin-C . . . that this vitamin is necessary in particular for the development and maintenance in good condition of the bone system, of the teeth and gums. That the absence of this vitamin lowers the resistance of the organisms to infections.

For vitamin-D . . . that in rational combination with other vitamins, it favors the normal process of calcification of bones and of the teeth. In the case of a foodstuff containing vitamin-D, one must mention as a rule the daily consumption of food which must not be exceeded.

If in a food product the simultaneous presence of two vitamins has been stated, one in considerable and the other in unimportant quantity and in irrational combination, the second vitamin may not be mentioned without expressly specifying that it is in insufficient quantity.

C.

Preservation of Standard Solutions.—NORRIS W. MATTHEWS (*Chemist Analyst*, 1933, XXII, Nos. 4, 5) recommends the addition of nitric acid (3 drops per liter) to standard solutions of silver nitrate, as a preservative to prevent the deposition of metallic silver. Addition of nitric acid (1 cc. per liter) to standard solutions of potassium thiocyanate (sulphocyanide) acts as a preservative, preventing the growth of fungi. Solutions of sodium thiosulphate containing 0.5 per cent. of amyl alcohol by volume become clear in a few days, and do not decompose or change in normality for months.

J. S. H.

Removal of Cod Liver Oil Stains.—A writer in *Patchwork* (1933, XVI, No. 6, 2–3) recommends the following procedure for the removal of cod liver oil stains from fabrics. The stained material is soaked in kerosene oil for one hour, and rubbed slightly at intervals to work the oil thoroughly into the stain. Then the fabric is placed in water containing shaved naphtha soap; and the water is boiled for approximately ten minutes. Clear, warm water is used for rinsing. This procedure is usually effective.

J. S. H.

Engineering in 1933.—(*Science Service.*) The steamship "Rex" of the Italian Line won transatlantic laurels by crossing in 4 days, 13 hours and 58 minutes, a distance of 3,181 miles.

Sir Malcolm Campbell made a new world's automobile speed record of 272.108 miles an hour at Daytona Beach, Florida.

The world's largest dry-dock, capable of accommodating a vessel of 100,000 tons if such a ship should be built, was completed at Southampton, England.

Rifle bullets that speed a mile a second and which are squeezed down a tenth of an inch of their diameter as they pass through the rifle bore were investigated by the U. S. Army.

Stainless invar steel, combining rust resistance with small temperature expansion was invented by Dr. Kotaro Honda, Japanese Scientist.

A radio range beacon improvement that allows the aviator to determine his direction from four different signals sent in the four directions was developed by F. W. Dunmore.

Dr. E. F. W. Alexanderson has invented a new type of alternating current electric motor for variable speeds which is synchronous, has no commutator and is controlled by a vacuum tube.

A new electric watch timer utilizes a constant frequency current and makes possible watch regulation in ten minutes instead of ten days.

A servo-mechanism machine that controls another machine with alertness, speed and accuracy was developed at the Massachusetts Institute of Technology for operating calculating machines.

A photographic camera-projector which copies onto motion picture film newspaper pages for file purposes was perfected commercially.

A camera lens of relative aperture F. 0.85, about fifty times the speed of ordinary camera lenses, was developed in Germany.

The world's tallest radio tower, 878 feet, was erected in Nashville, Tenn.

The first practical use of aluminum alloy in bridge construction occurred when it was used to reconstruct the floor of a Pittsburgh bridge.

A sodium-vapor highway lamp of 10,000 lumens was developed by the General Electric Company.

Construction was started on two water-turbine generators for Boulder Dam greater in capacity and size than any previously constructed.

An inductor telephone system for communication between the head and rear ends of long freight trains, between nearby trains or between trains and wayside points has been perfected.

Preliminary operation of two mercury-vapor turbines of 20,000 kilowatts capacity was started.

New designs of fans give increased air volume for a given power input with quiet operation.

The largest diesel engine plant in United States, containing five 7,000 horsepower diesels was put into operation at Vernon, California.

Multiparty toll service or toll conference was made available to many telephone stations throughout the country.

The longest direct cable circuit in the world, 1850 miles from New York to Dallas, Texas was established.

A 5700-foot vehicular tunnel running under Boston harbor, is nearing completion.

The fastest elevator, operating at 1400 feet per minute was put in service in a 69-story office building of Rockefeller Center, New York.

The country's largest radio station, 500-kilowatt W8XO, being built for experimental use by the Crosley Co. was almost completed.

Newark Museum Exhibit.—We are informed that the Newark Museum of Newark, N. J., has in the course of preparation an exhibit of industrial chemistry for the layman. More than one hundred national firms have accepted an invitation to coöperate in the exhibit which will open about the middle of March.

The purpose of the Museum's exhibit is to dramatize the many ways in which chemistry influences everyday life. In one section will be shown rooms furnished completely with materials created by chemistry. In the section devoted to textiles and clothing will be shown figures dressed completely in substitute materials. The story of the skyscraper and the many contributions which chemistry has made to the building trades will be featured in another exhibit. Other sections will deal with research chemistry, industrial wastes, corn products, coal tar, plastics, sulphur and sulphuric acids. A series of educational moving pictures dealing with chemistry is also being arranged.

C.

Roman Road Construction.—A day on the Appian Way, the most famous road of ancient Rome, is visualized in the large scale model of a Roman road prepared by the Bureau of Public Roads. This model shows both the construction of the road and the traffic on the highway. It will be located permanently in the National Museum in Washington.

The Appian Way, one of the main roads of the Roman Empire highway system, has so far lasted twenty centuries. In the light of present-day practices such a road would be considered wasteful because its cost would be six times as much as the wide modern highways built for heavy traffic. The Appian Way was 16 feet wide with 2-foot curbs 18 inches high on both sides beyond which were 8-foot side roads. It was constructed of solid stone and concrete masonry 3 to 4½ feet thick depending upon the soil over which it was laid. It was very straight, with steep grades and the curves widened as on modern roads. The chief difference between the ancient Roman road and the modern highway is that the present-day engineer relies upon the soil to bear the load; the pavement should act as a wearing surface and a roof to protect the supporting subgrade soil. The Romans relied solely upon massive construction.

In building the Appian Way, a bed of sand and gravel sometimes covered with a thin coat of lime mortar was used as a foundation for the four layers of masonry. The first masonry layer, from 10 inches to 2 feet thick, was composed of stones that would fit in a man's hand held together with lime mortar or clay. The second layer of smaller stones mixed with lime mortar was 9 inches thick.

The third layer was a concrete made of small stones, sand and hot lime mortar 1 ½ feet thick in the center and a foot thick on the sides. The fourth or wearing layer was of polygonal stones about 3 feet in diameter and 6 inches thick laid with close joints. The upper surfaces of the wearing stones were dressed smooth and the joints so tight they were scarcely discernible.

The traffic then would hardly be so heavy or so plentiful as that of today. Slave-borne litters with their occupants of high rank must have passed with considerable frequency. The popular two-horse chariots speeding by typified the Roman sporting element. Wagons drawn by many yoke of oxen creaked slowly, hauling produce and freight. Couriers of the imperial post, which was fast and frequent, sped on their way. Soldiers marched proudly by beggars seated on the curbs. The sidewalks were thronged with people.

C.

The Pittsburgh Award.—The Pittsburgh Section of the American Chemical Society has selected Dr. Ralph E. Hall, Director, Hall Laboratories, Inc., Pittsburgh, Pa., as the recipient of the 1933 (the first) Pittsburgh Award. This award was made in recognition of Dr. Hall's distinguished service to chemistry and humanity, particularly his contributions to the fundamental knowledge of boiler-water reactions and their applications to the practical solution of boiler-water problems, his discoveries and technical accomplishments in the beneficiation and conditioning of water for industrial and domestic use, and his developments in the production of chemicals for these purposes.

C.

Beer Kegs of Red Oak.—The U. S. Department of Agriculture announces that the Forest Products Laboratory has developed a method for rendering barrels of red oak impervious to the leakage of liquids and gases. The wood of red oak is naturally porous and therefore unsuitable as a substitute for its cousin, the white oak now being used almost exclusively in the making of casks and kegs. A natural deposit called "tyloses" plugs the pores of white oak during growth, whereas in red oak "tyloses" are absent. The Laboratory found that red oak barrels could be made as tight as a white oak container simply by treating the inside with hot liquid pitch under pressure. Although white oak has a decay resistance superior to red oak, most barrels of this type wear out before they rot.

C.

A Congress of Electro-Radio-Biology.—The First International Congress of Electro-Radio-Biology is scheduled to take place in Venice in September, 1934. All subjects concerning oscillatory and corpuscular phenomena in relation to biology will be examined and discussed: ultra-sounds, electric waves, infra-red, light, ultra-violet, radium, penetrating radiation in its probable influences on the various manifestations of organic and organized matter and in applied laboratory work; photodynamic actions, long-distance actions of metals, Gurwitsch rays, phenomena of luminescence, radiations of radio-active salts in organic combinations; electric states of the atmosphere; spectroscopy; influences of radiating energy on heredity and so on.

The most prominent figures in physics, chemistry and present day biology will give lectures in their special fields after which will follow talks of a more strictly radio-biological nature. It is to be a fundamental congress based on new and universal foundations in which those whose studies have a bearing on all matters related directly or indirectly with the subject will exchange their own ideas, thus tending to reach a program of unification in the promising field of radio-biology.

C.

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